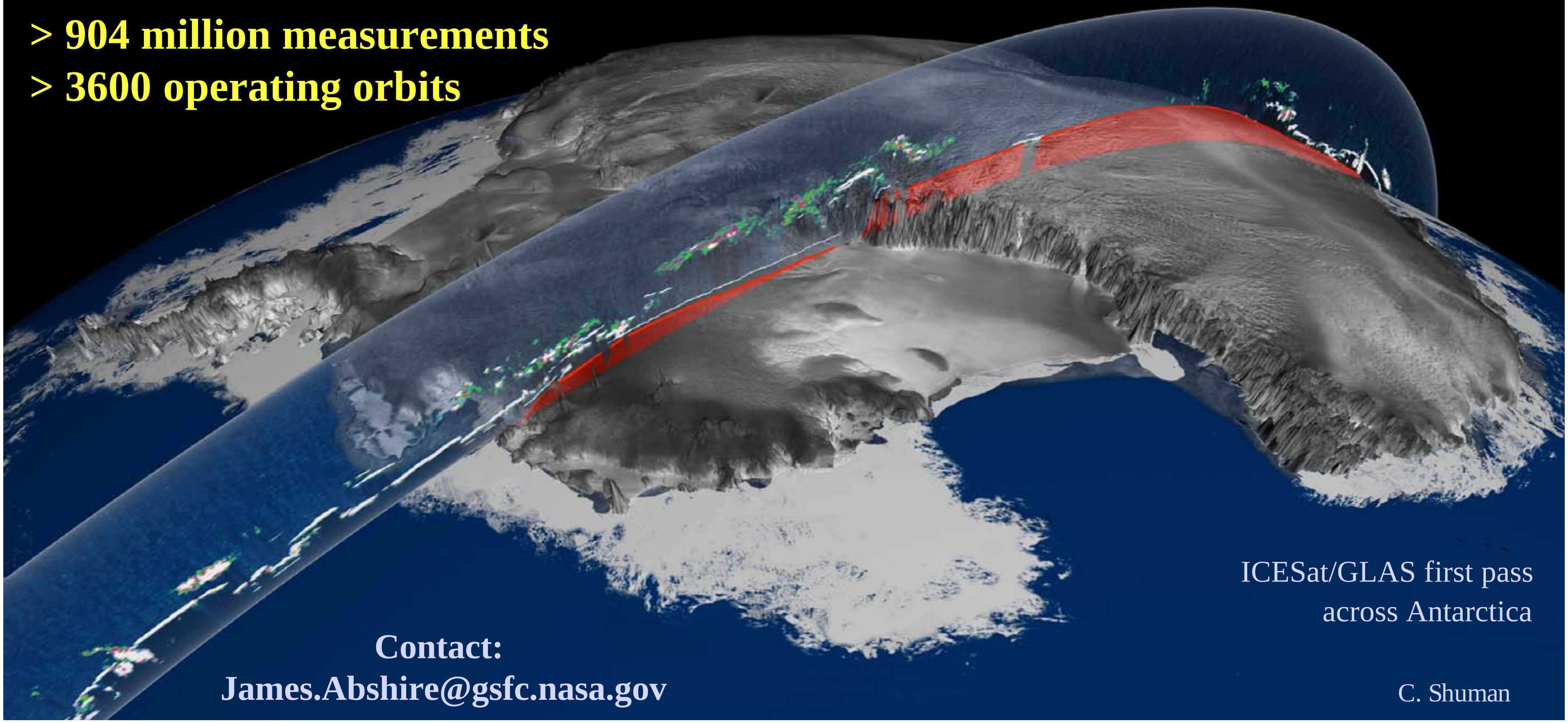
Geoscience Laser Altimeter System (GLAS) on ICESat Mission - Science Team Update

GLAS Instrument Team and GARB3

October 13, 2005

> 904 million measurements
> 3600 operating orbits



ICESat/GLAS first pass across Antarctica

C. Shuman

Contact:
James.Abshire@gsfc.nasa.gov

Summary & Outline

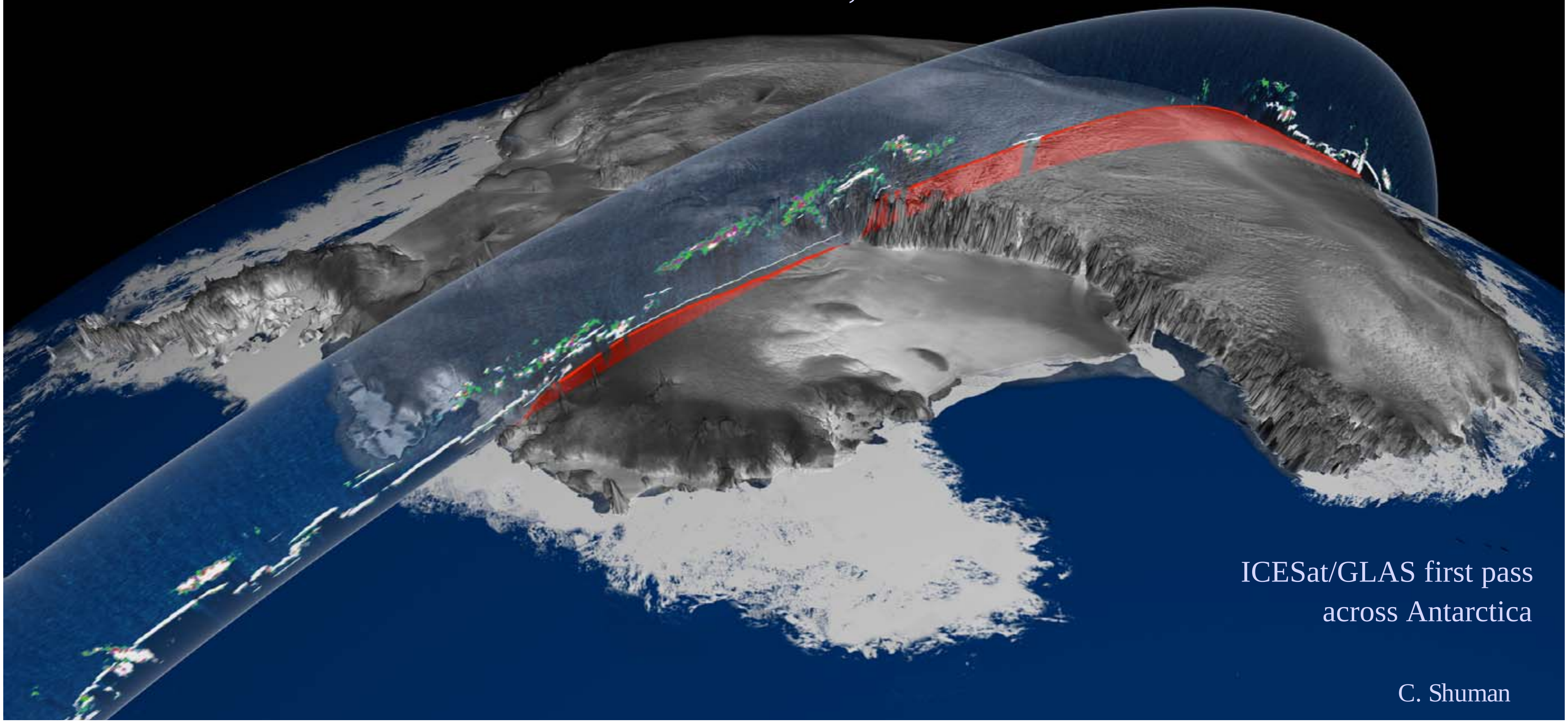
Outline:

- GLAS Laser & GARB Update - Jim Abshire, Pete Liiva, Graham Allan, Haris Riris
- GLAS Receiver Update - Xiaoli Sun
- GLAS Altimetry Echo Pulse Energy & Saturation Update - Xiaoli Sun et al.

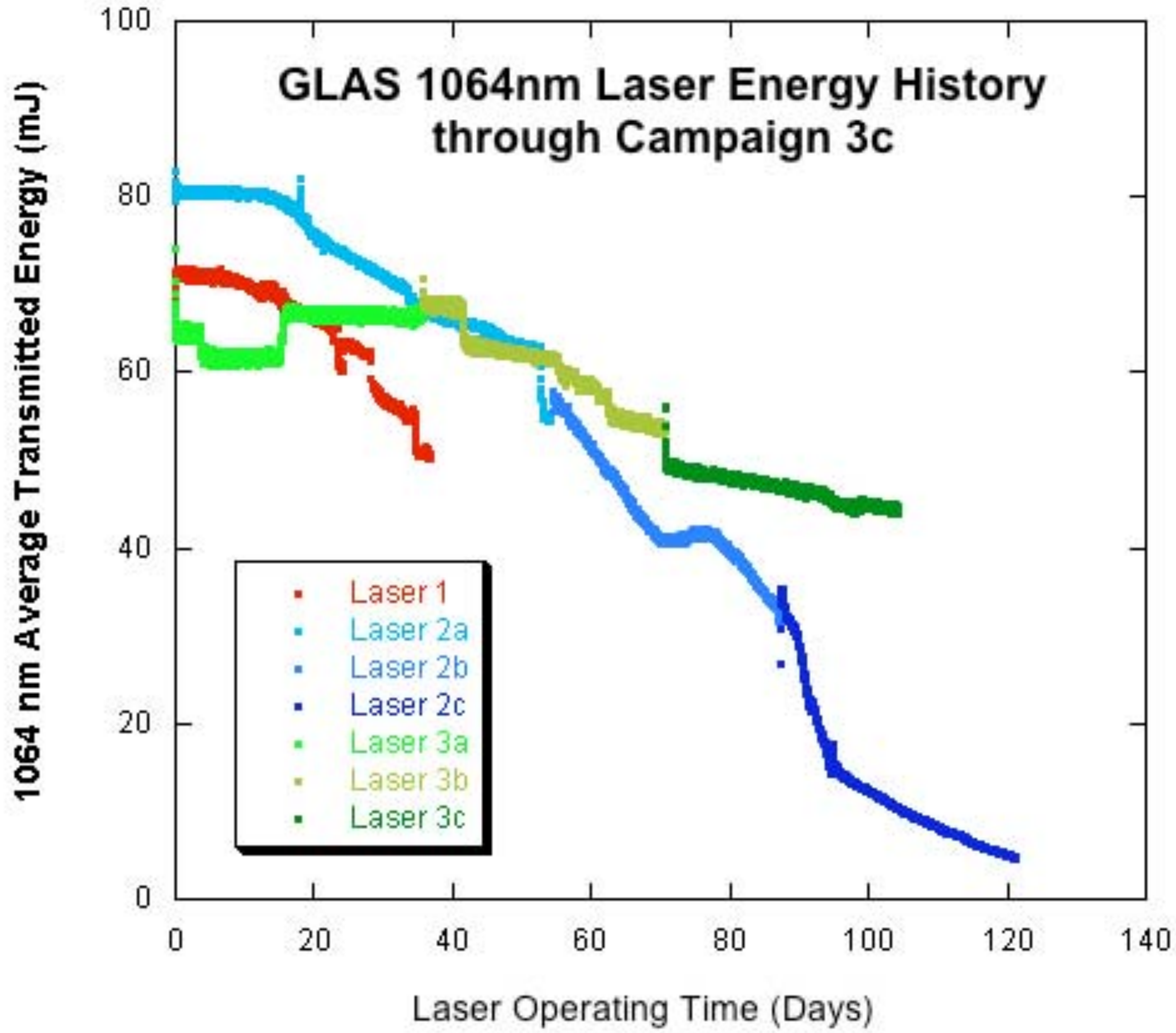
Geoscience Laser Altimeter System (GLAS) on the ICESat Mission: Laser Update

James B. Abshire, Pete Liiva, Graham Allan and GARB3

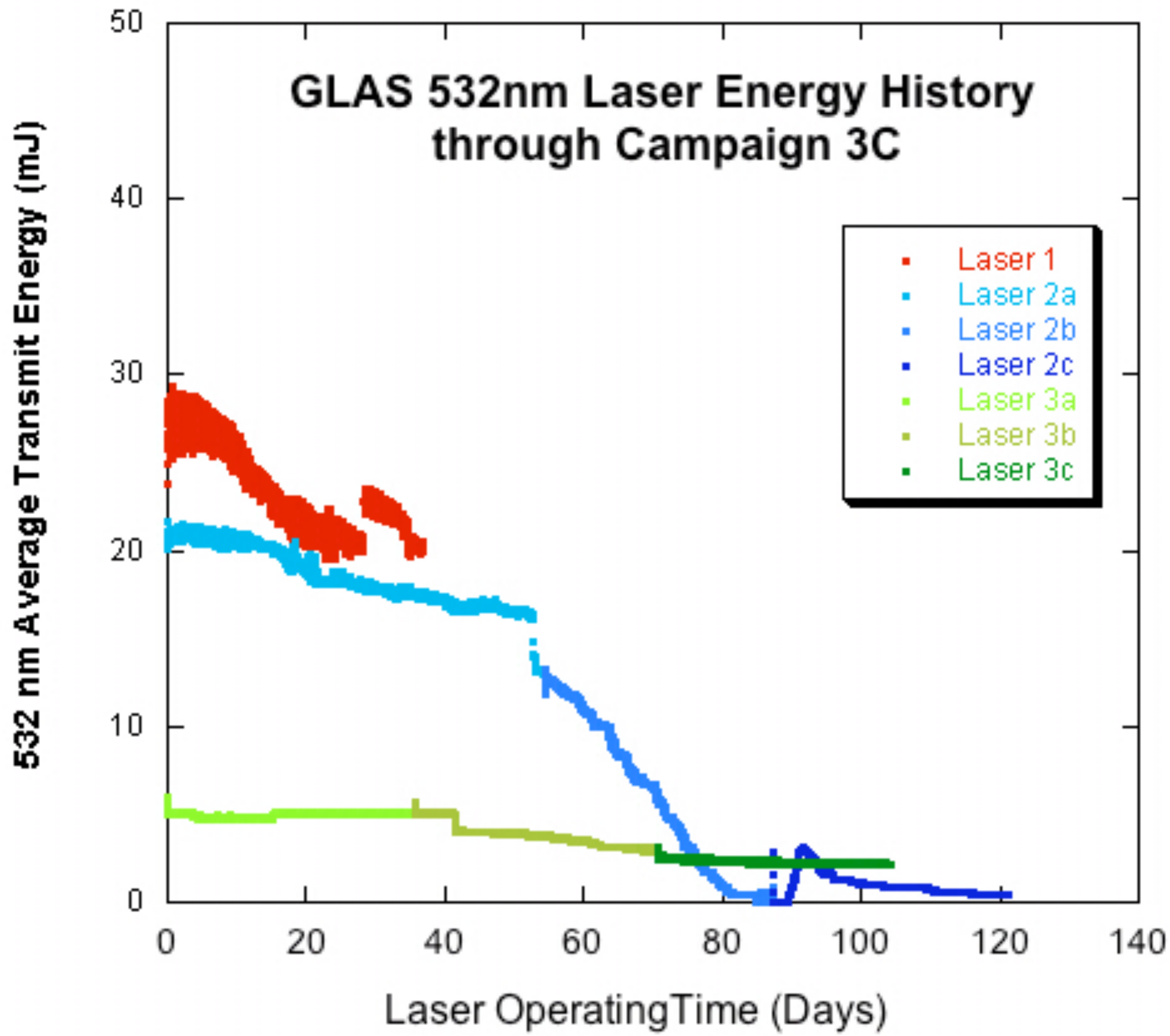
October 13, 2005



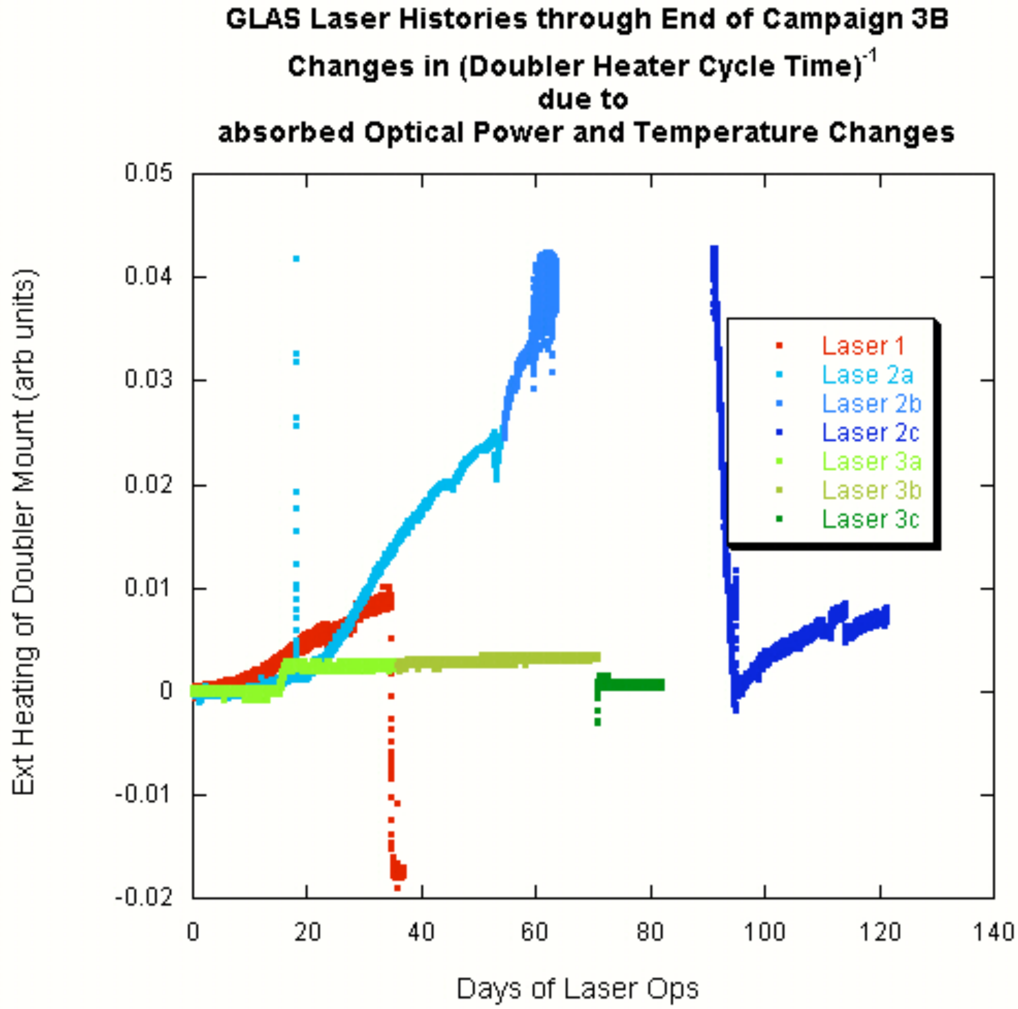
1064 nm & 532 nm Energy Histories



1064 nm & 532 nm Energy Histories



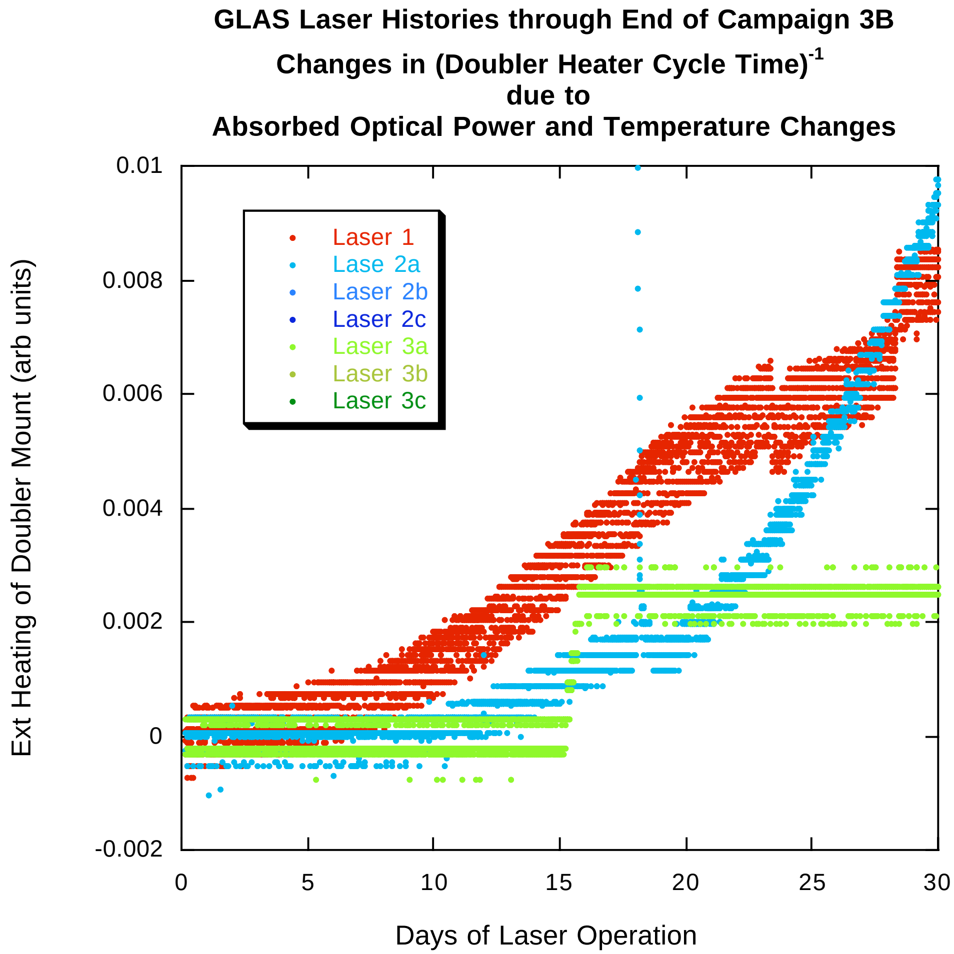
Laser Doubler External heating (doubler absorbing laser power): All lasers thru 3b



Differences for Laser 3:
1. Longer in space before ops
2. Colder during all ops
3. Lower 532 nm energy

	Units	Laser 1	Laser 2A	Laser 2B	Laser 2C	Laser 3A	Laser 3B	Laser 3C
Time in space before 1st laser firing	Days	39	256			630		
Laser Reference Temp. Start	C	29.0	26.6	26.8	26.8	13.8	16.0	13.8
Time at Start Reference Temp.	days	34.5	54.2	32.8	2.0	15.0	35.0	13.6
Laser Reference Temp. End	C	22.0	26.8	26.9	16.8	16.0	16.0	13.8
532 nm Energy Start	mJ	28.0	21	12.9	0.0	5	5	2.6
532 nm Energy End	mJ	20.0	13.0	0	0.4	5.0	2.9	2.3

Laser Doubler External heating (ie doubler absorbing laser power): 1st 30 days of ops for each laser only



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GLAS Lasers: An Analysis of Laser Induced Heating of the GLAS Doubler Crystals (preliminary)

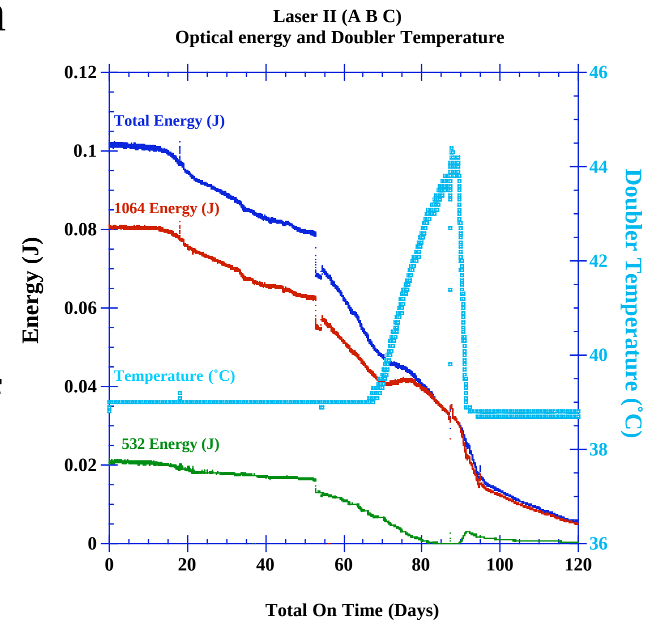
Graham Allan
Sigma Space
August 2005

Can laser induced heating of the doubler crystal explain some of the GLAS laser's on-orbit behavior ?

- Decay in Optical Energy?
- Temperature Rise?
- FF Mode Structure?

Doubler Heating Model Assumptions

Model GLAS Doubler Temperature Distribution



Heat loss:
Conductive and radiative heat/energy transport

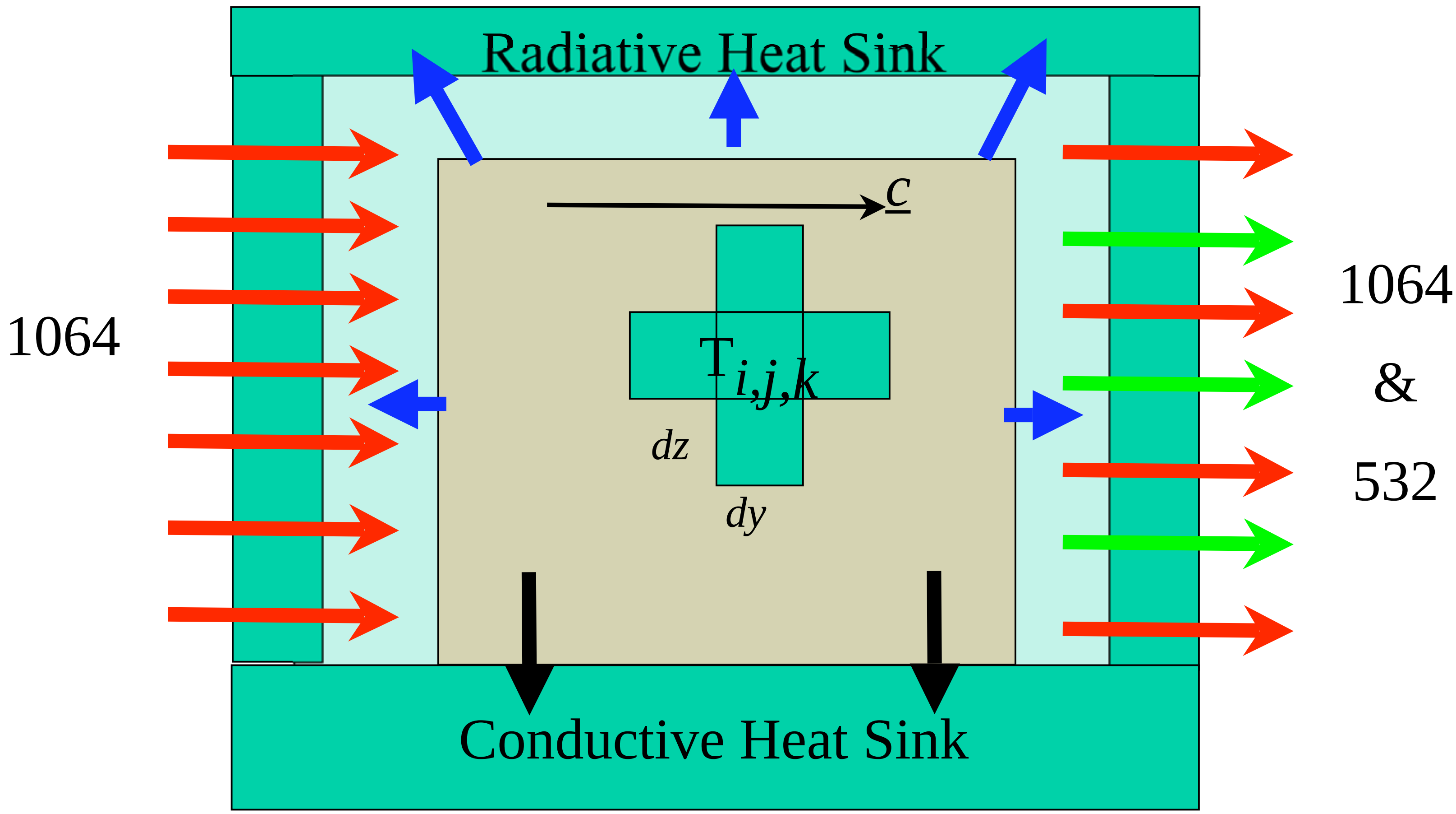
Heat Gain:
Direct heating of one face from absorption of laser energy

Temperature sensitivity of phase matching

Predict 532 nm energy, 1064 nm energy, total optical energy, crystal temperature and intensity profile of the transmitted light.

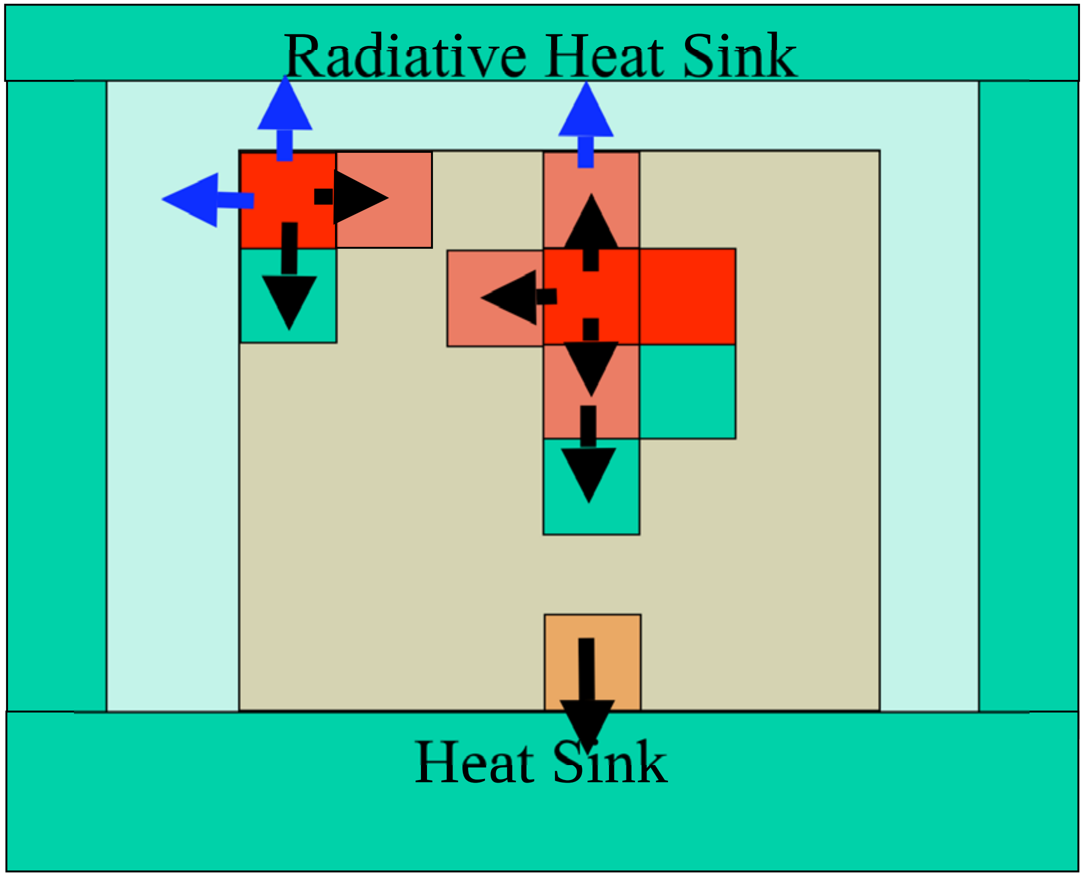
Assume the heating is proportional to the accumulated green energy

2D-Thermal Model of the GLAS Doubler Crystal



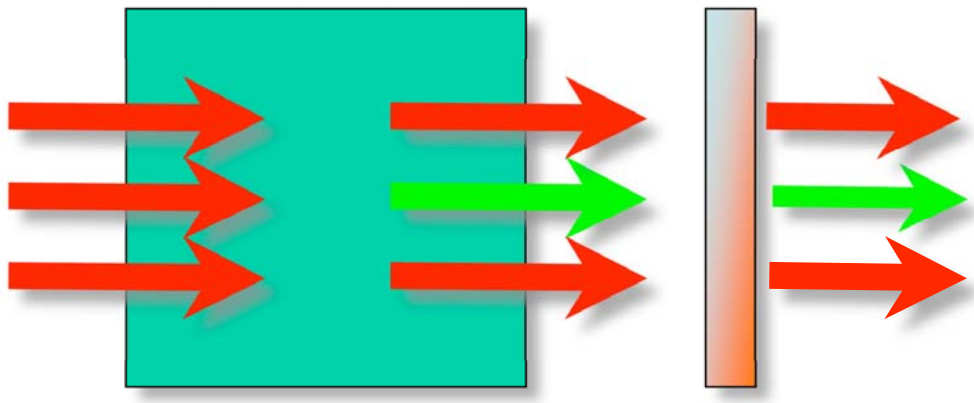
X-tal is divided into an array of *n* volume elements *dx.dy.dz*
And point temperatures $\{T_{i,j,k}\}$.

2D Heat (*Energy*) Flow & the Delta Temperature matrix $\{DT_{j,k}\}$



Local temperature gradients are calculated. Thermal Energy Flow (*time step, conductivity tensor* $k_{i,j,k}$ *Specific heat C, Elemental Volume, Mass, X-sectional Area)*

Photo-Generation of an Optical Absorption



- Model assumed that a two-photon process can generate an absorbing layer through a process not specified in this model.

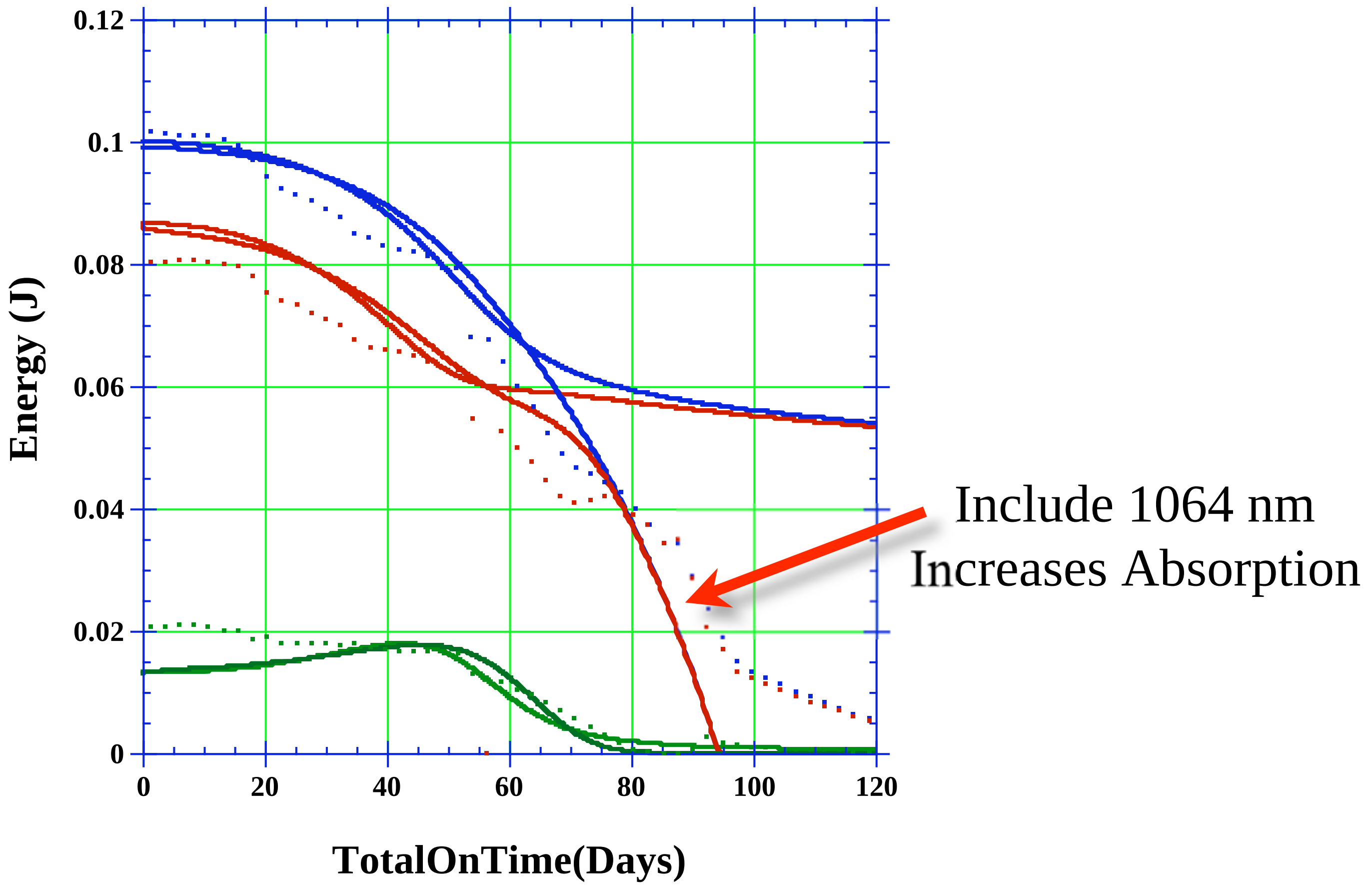
- GARB working hypothesis is photo-darkening of trace hydrocarbons gas from adhesive

- This process is dependent on the total exposure to the "square of the green intensity".

- It is also assumed that a percentage of absorbed IR light generates further absorption.

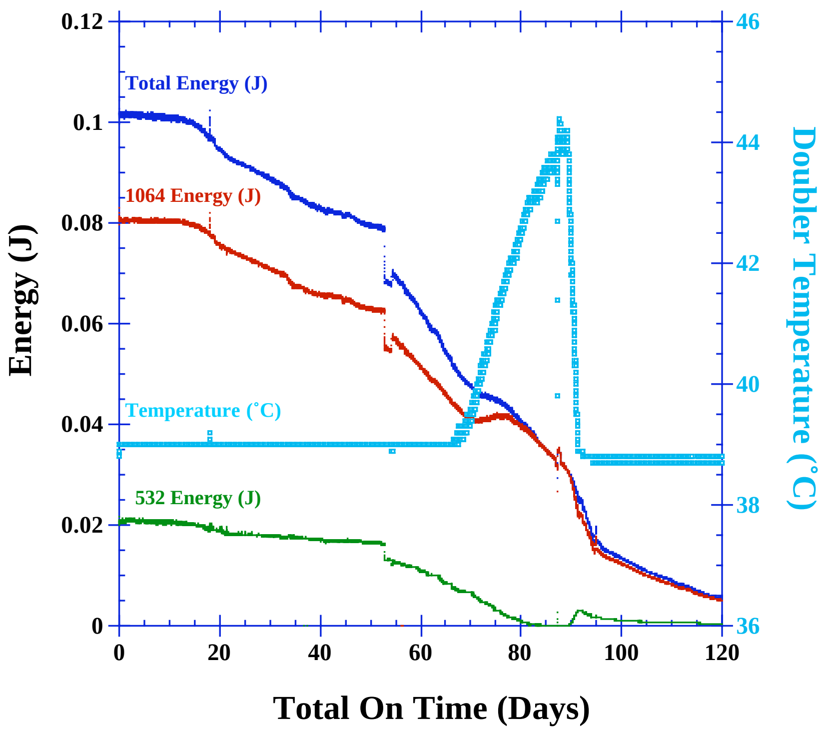
Numerical Fit to the data: Laser 2 On-Orbit Data

Heading--Optical Absorption -- Cumulative 532 nm Intensity^2 --Percentage of 1064 nm

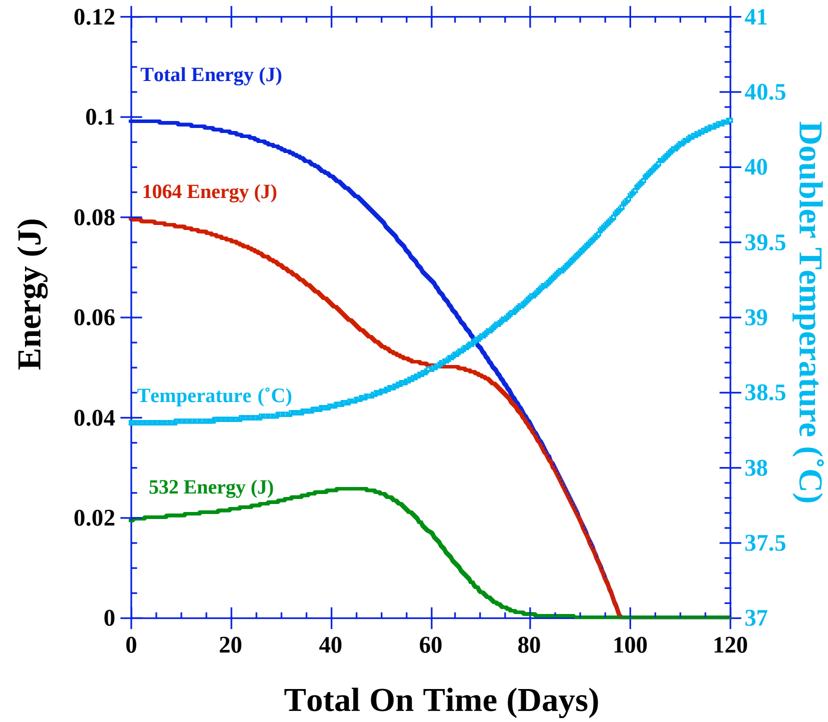


Preliminary Comparison of Numerical Model and Data from Laser 2 (a,b,c) March 2004

Actual Laser 2



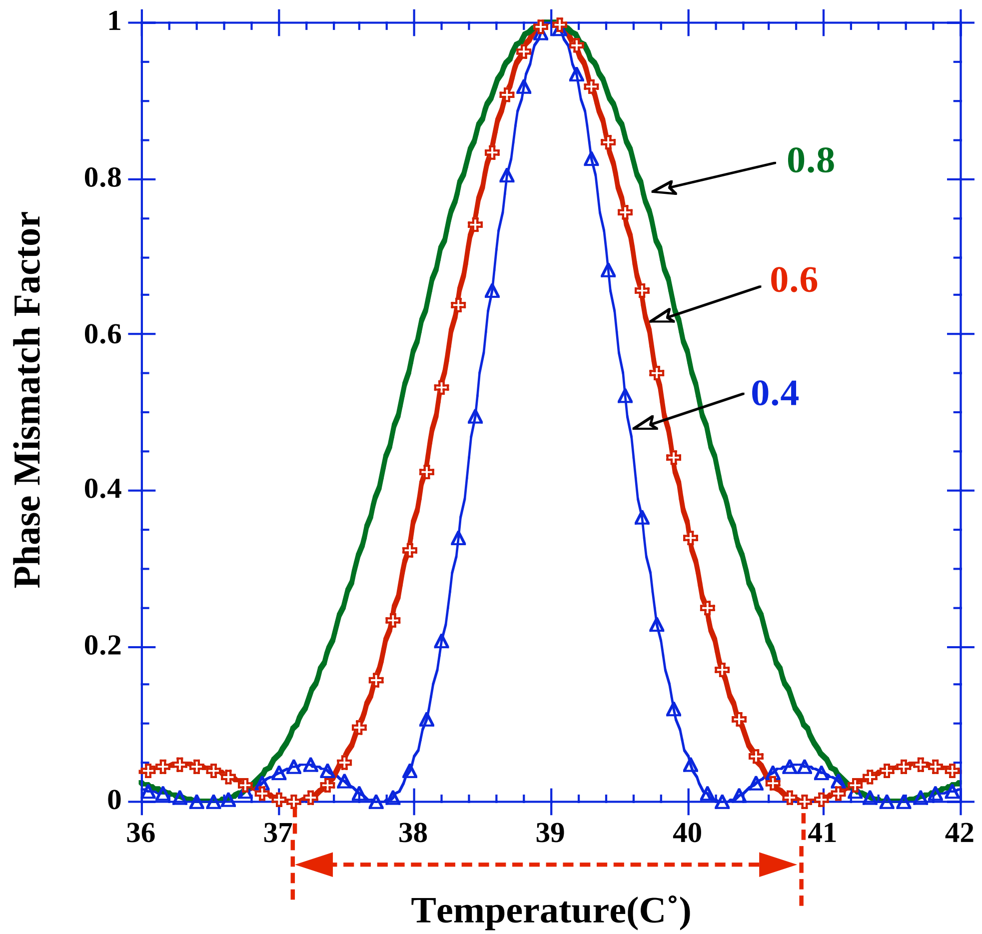
Numerical model



- The model qualitatively predicts the observed behaviour
- The predicted temperature rise is smaller than measure (Core Temperature)
- After ~90 days the Laser 2’s doubler set point was changed.

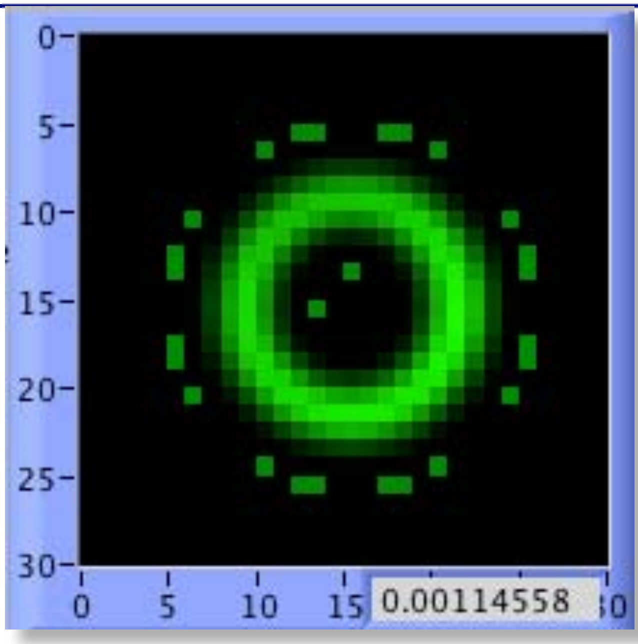
Doubler - Temperature Dependent Phase-Matching

Temperature BandWidth Doubler



$$\text{Phase Mismatch} = \frac{\sin^2(2\pi(T\text{-}To)/\Delta T)}{(2\pi(T\text{-}To)/\Delta T)^2}$$

Comparison of Model prediction with Laser 1 FF 532 nm image (assuming cirrus cloud illum)



- The axial temperature gradient caused by laser heating is sufficient to thermally de-tune crystal from optimal phase-matching
- It " detunes the doubling" in the center of beam
- The radial thermal gradient allows for some conversion of IR to green toward the edge

- Long-exposure visible light photograph of a GLAS over-flight of Colorado on March 12, 2003 (Ball Aerospace)
- Shows "donut" structure in 532 nm beam
- Beam pattern consistent with optically induced thermal heating of laser's doubler crystal

GLAS Laser 3
Estimates of Useful Lifetime Remaining after 3C Campaign

Draft

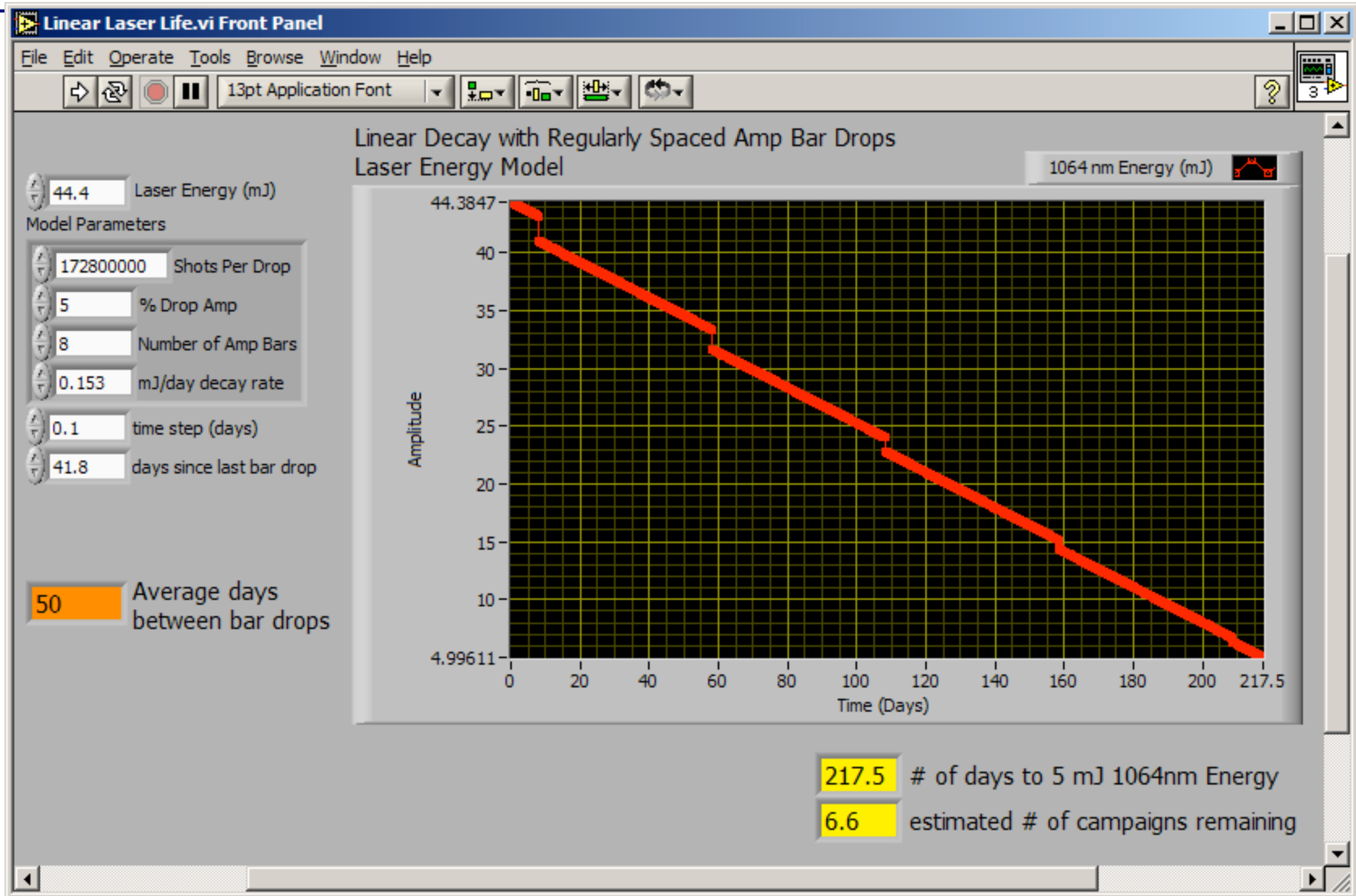
Peter Liiva
Sigma Space Corporation
7-27-05

Laser 3 Remaining Useful Life Estimates

- All estimates are from the end of Laser campaign 3C onward.
- The Laser gradual decay rate is assumed to be linear.
- End of Laser life assumed to be 5mJ of 1064nm energy output.
- Estimates do not include the likelihood of the Laser 1 bar-blow out failure (low, but finite).

Regular Bar drop Estimates:

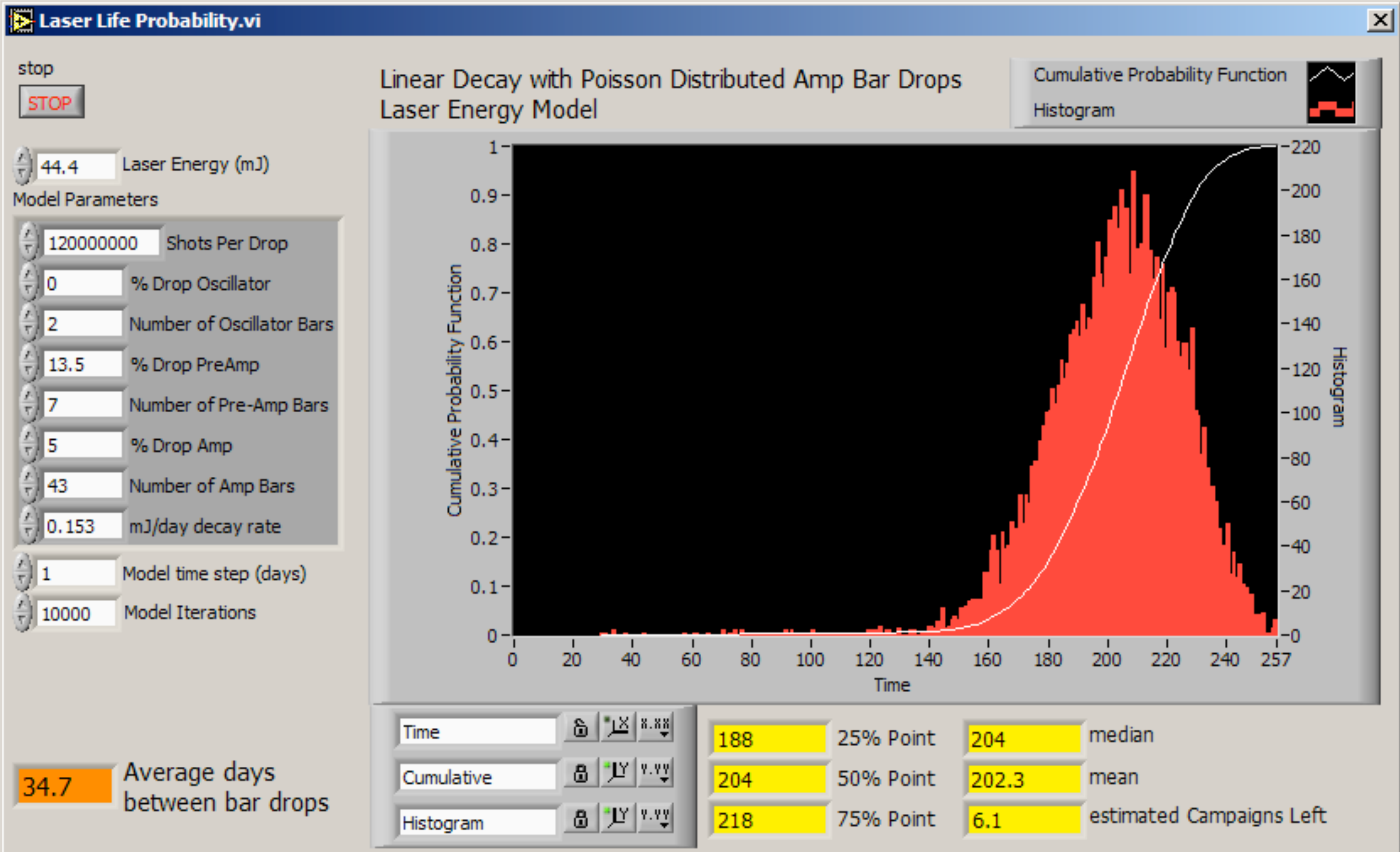
- Calculated for three different periods between bar drops, based on different estimates:
  - 172.8 Mshots/drop (50 days/drop)
  - 120 M shots/drop (34.7 days/drop)
  - 94 M shots/drop (27.2 days/drop)
- Starting with 1064nm laser energy at 44.4mJ (end of Laser 3C campaign)
- Linear energy decay rate taken from Laser campaign 3C (-0.153 mJ/day)
- 5% drop due to each amplifier bar drop


Linear Laser Life.vi Front Panel
File Edit Operate Tools Browse Window Help
13pt Application Font
Linear Decay with Regularly Spaced Amp Bar Drops
Laser Energy Model
1064 nm Energy (mJ)
44.4 Laser Energy (mJ)
Model Parameters
172800000 Shots Per Drop
5 % Drop Amp
8 Number of Amp Bars
0.153 mJ/day decay rate
0.1 time step (days)
41.8 days since last bar drop
50 Average days between bar drops
Amplitude
44.3847
40
35
30
25
20
15
10
4.99611
0 20 40 60 80 100 120 140 160 180 200 217.5
Time (Days)
217.5 # of days to 5 mJ 1064nm Energy
6.6 estimated # of campaigns remaining

Linear decay rate model with "Poisson-distributed" bar drops

- Linear decay rate taken from Laser campaign 3C (0.153 mJ/day)
- "Poisson-distributed" bar drops
- Model assumes equal probability that any single bar can drop-out from the full complement of the *remaining* bars.
- Model does NOT take into account that oscillator bars are driven by less current

- Model assumes:
  - No drop due to a single oscillator bar (because of the passive Q-switch & compensating electrical driver)
  - End of life if have a 2nd oscillator bar drop
  - 13.5% drop due to pre-amplifier bar
  - 5% drop due to amplifier bar
- Model run for 10,000 iterations and probability distributions collected.



Laser Life Probability.vi
stop
STOP
44.4
Laser Energy (mJ)
Model Parameters
120000000
Shots Per Drop
0
% Drop Oscillator
2
Number of Oscillator Bars
13.5
% Drop PreAmp
7
Number of Pre-Amp Bars
5
% Drop Amp
43
Number of Amp Bars
0.153
mJ/day decay rate
1
Model time step (days)
10000
Model Iterations
34.7
Average days between bar drops
Linear Decay with Poisson Distributed Amp Bar Drops
Laser Energy Model
Cumulative Probability Function
Histogram
Cumulative Probability Function
Histogram
Time
0
20
40
60
80
100
120
140
160
180
200
220
240
257
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
100
120
140
160
180
200
220
Time
Cumulative
Histogram
188
25% Point
204
50% Point
218
75% Point
204
median
202.3
mean
6.1
estimated Campaigns Left

Summary
Estimates of Remaining Laser 3 Useful Life

Bar Drop Period Estimate (Mshots/drop)	Regularly Scheduled Bar Drops (days)	Regularly Scheduled Bar Drops (campaigns)	25% lifetime Poisson distr Bar drops lifetime(days)	Mean Lifetime Poisson-distributed Bar Drops (days)	75% lifetime Possion distr bar drops (days)	Mean lifetime Poisson-distributed Bar Drops (campaigns)
173	217.5	6.6	203.0	218	231	6.6
120	205.1	6.2	188.0	204	218	6.2
94	194.5	5.9	177.0	192	207	5.8

- All calculations give ~ 6 campaigns remaining lifetime to 5 mJ for Laser 3, assuming no sudden failure
- Primary term influencing estimated lifetime is linear decay of energy vs time
- Estimates assume this gradual decay rate will stay constant
  - History shows sometimes gradual decay rates get worse after drops
  - It isn't clear why this happens
  - MOLA-2 laser had ~8 bar drop events, with no slope changes afterwards
- GARB is working to understand why this has occurred in GLAS lasers

Risk assessment for possible Sudden Shutdown -10/3/05

We held a special GARB meeting to consider Dave Hancock's question about the risk to the laser if the spacecraft were to suddenly go into safe-hold with the laser operating. This would result in ICESat suddenly removing electrical power to an operating laser & to GLAS. The GARB was asked to make a preliminary risk assessment this morning in order to guide a Laser 3D start date decision.

GARB participants included Rob Afzal, Pete Liiva, Danny Krebs, John Canham and myself. Also on the telecon were David Hancock, Ed Chang and Peggy Jester.

The primary question is how such a power off might effect risk areas in the laser. The largest concern was the rate of temperature change of the laser. The most vulnerable/fragile area in the lasers was thought to be the pump diode parts which contain gold bond wires which have been eroded from the growth of gold indide. The largest concentration of these (44 bars) are in the laser's amplifier stage. When the laser is operating these operate at about 9 deg C above the laser reference (box) temperature.

A normal laser power off results in a 9 deg drop in the temperature of these parts. Data furnished by Peggy Jester for the November 2003 stop fire event showed a laser reference temp change of about 2.5C/hour of the laser box, from 27C to 13.5 C in 5 hours. This change rate in the same ballpark as the 2 Deg C/hr laser temp change limit imposed by the GARB after the IGARB investigation.

The GARB reached a preliminary conclusion today that the temperature change from a sudden power removal from an operating laser would stress the bond wires in the pump diodes roughly the same amount as a normal laser power on/off cycle. Therefore the GARB's judgement was the risk to the laser from this event seemed roughly the same as a normal laser power cycle. Normally this risk is small, but the risk will increase as the degree of bond wire erosion increases. That is as the bond wires in these parts become thinner and more fragile.

Some additional work will be done in parallel to better understand the transient characteristics of the power supply upon sudden power removal, and determine if temperature transients were measured in the testing of the ETU lasers. The GARB will notify the project immediately if the results from additional work indicates an increased risk to the flight lasers.

GARB Status & directions

Status:

- Laser 3 continues to show better flight behavior than Lasers 1 or 2
- Lower temp has stopped apparent photo-darkening
- Extrapolation of present energy trends predict ~6 remaining campaigns to 5 mJ
- ETU Laser extended vacuum was completed
  - Surgery is underway - so far “very clean” doubler & optics
  - ETU history differences from flight lasers seem important
- Doubler darkening model seems consistent with observations lasers 1& 2

Staffing:

- Carolyn Krebs retired and handed off the chair to me
- LOLA effort is impacting avail time of others (Danny & Haris)
- Will use more time of Rob Afzal on GARB

Plans:

- Wrap up ETU surgery & report
- Give briefing on status & interim findings at GSFC
- Propose & conduct follow up experiments to resolve causes of surprises
- Wrap up documentation & report on the GARB activities

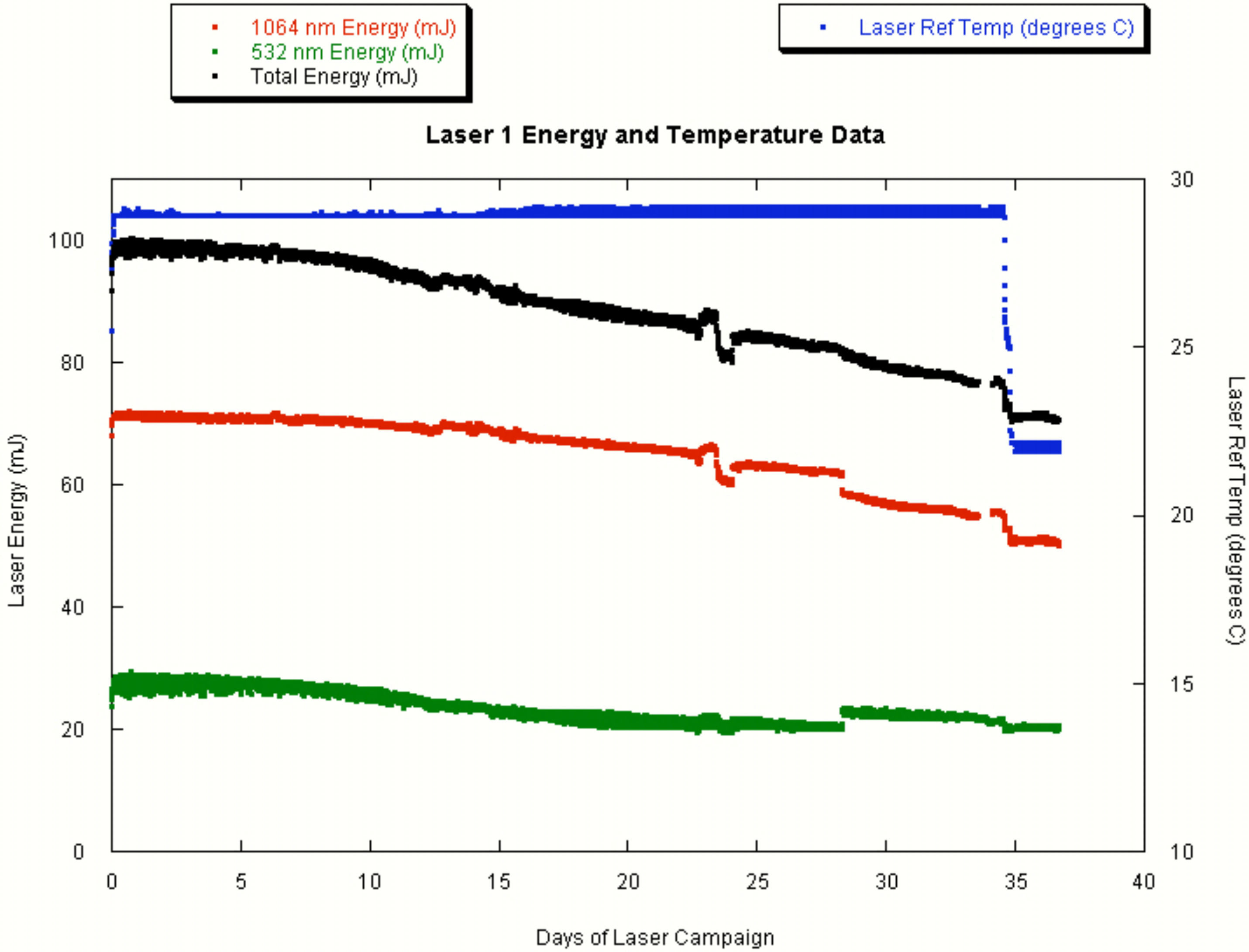
More Detailed Look at the Laser Operations for Each Campaign through 3C

Pete Liiva

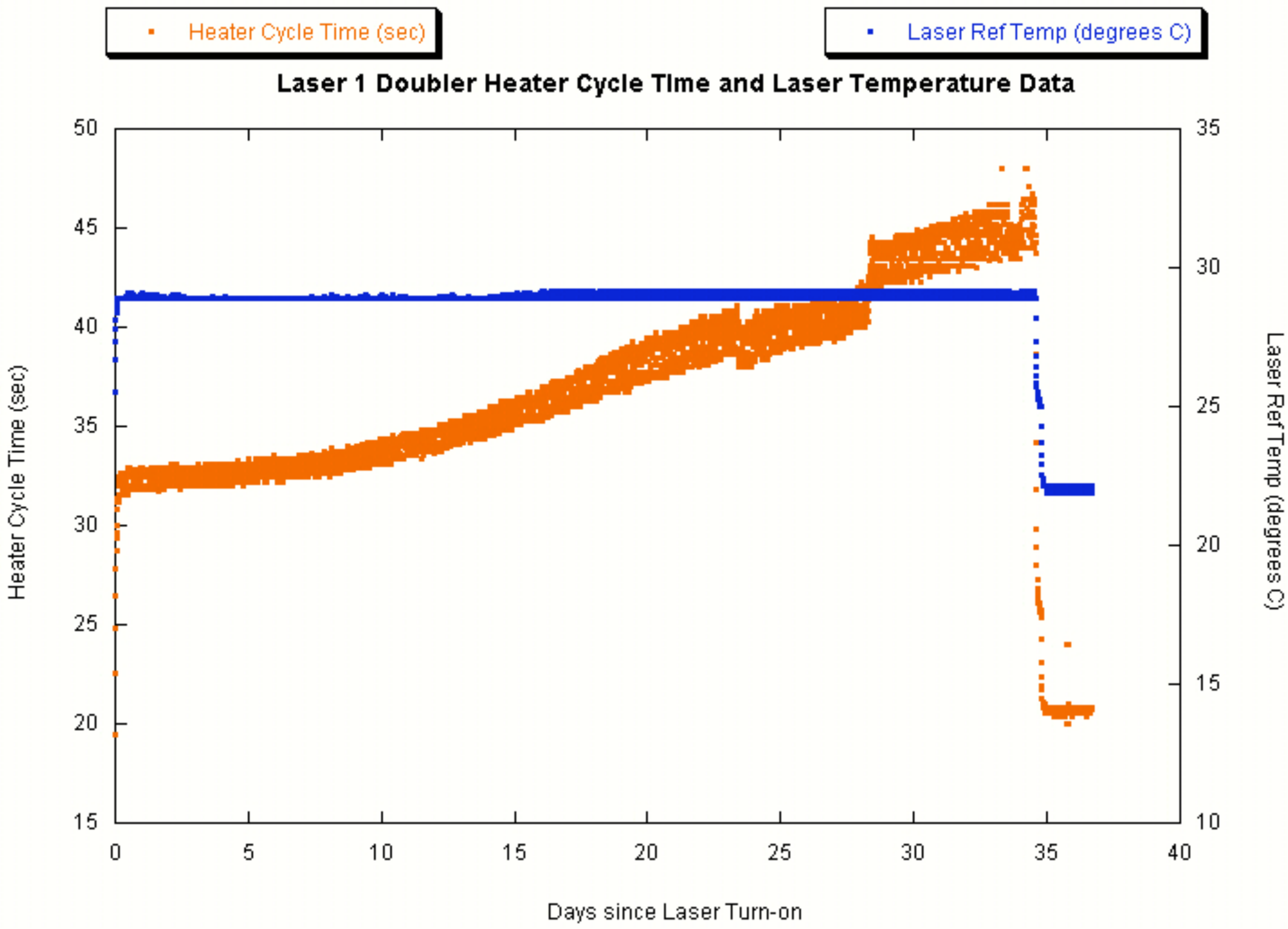
Days in orbit at start of use of each laser

	Days In Orbit Before Start
Laser 1	39.94443974
Laser 2	256.7291624
Laser 3	630.9113993

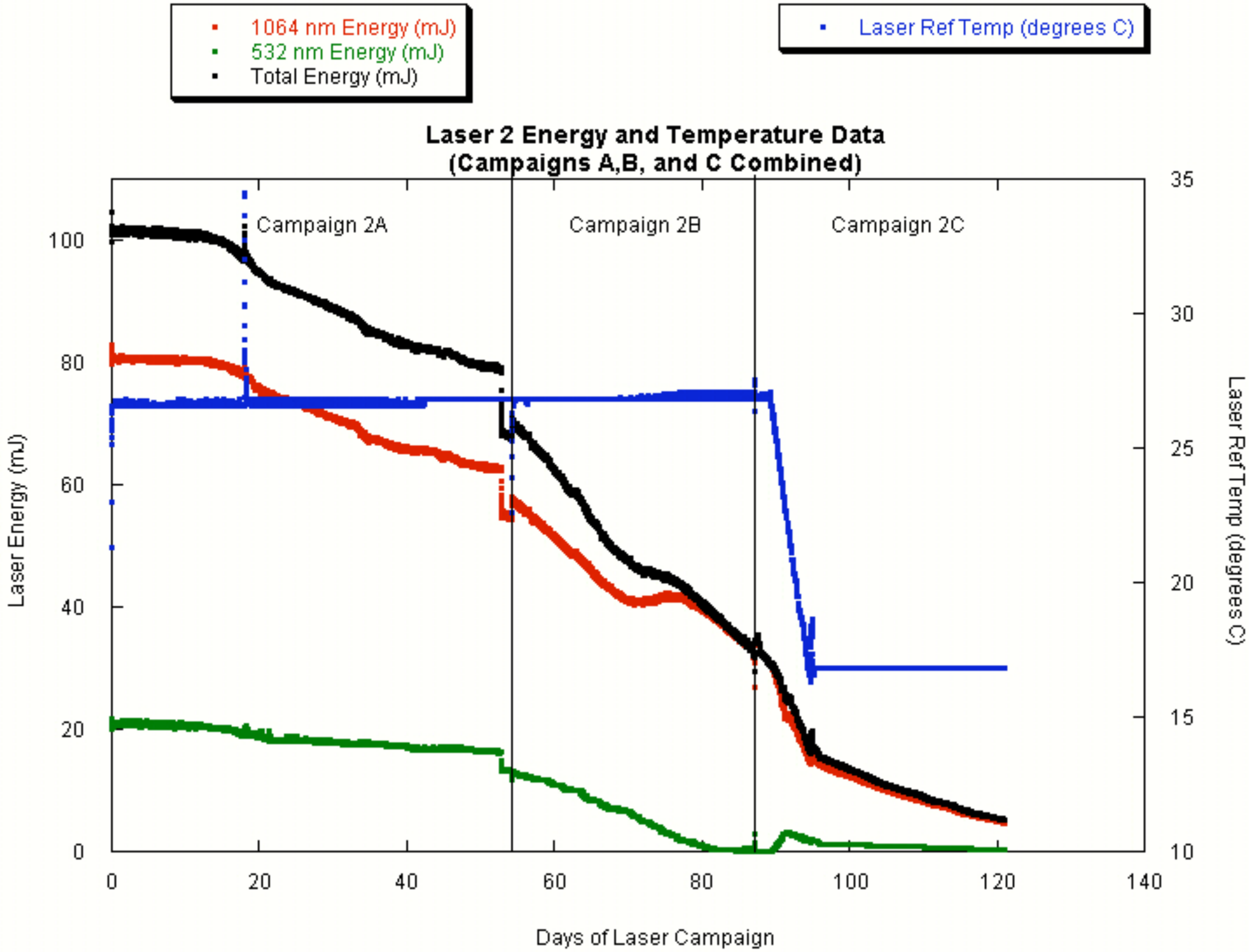
Laser 1 Campaign



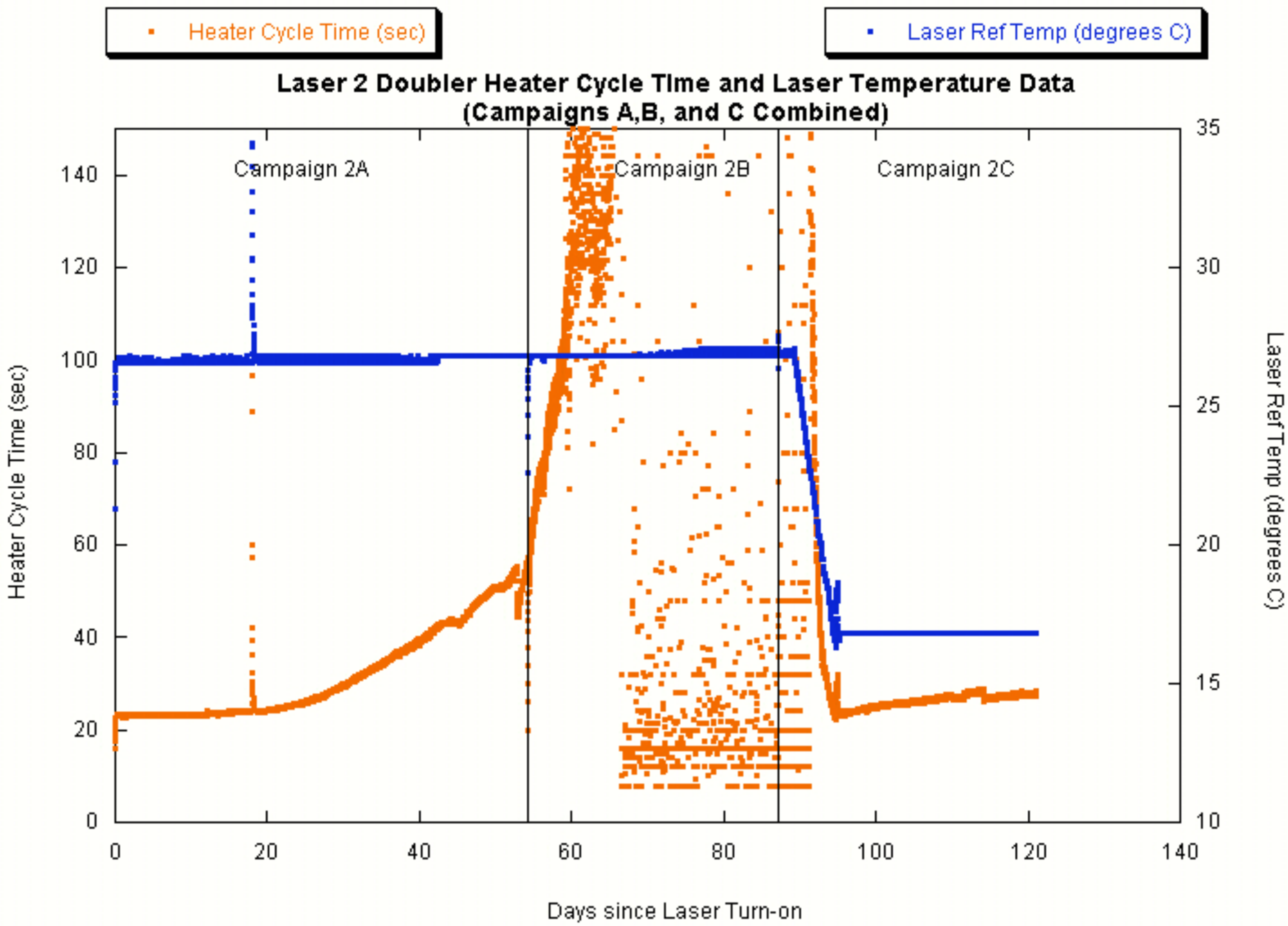
Laser 1 Campaign



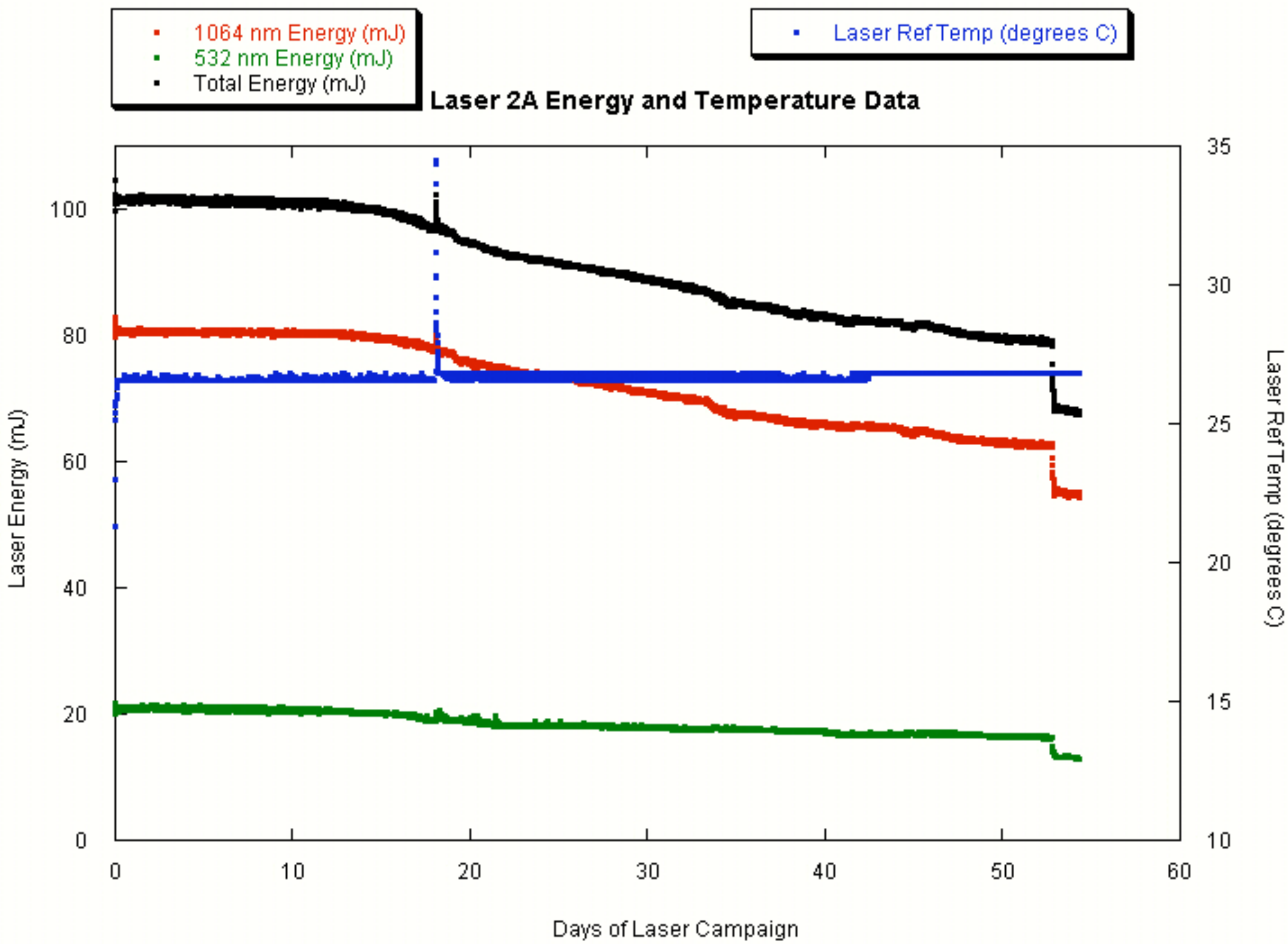
Laser 2 Campaign



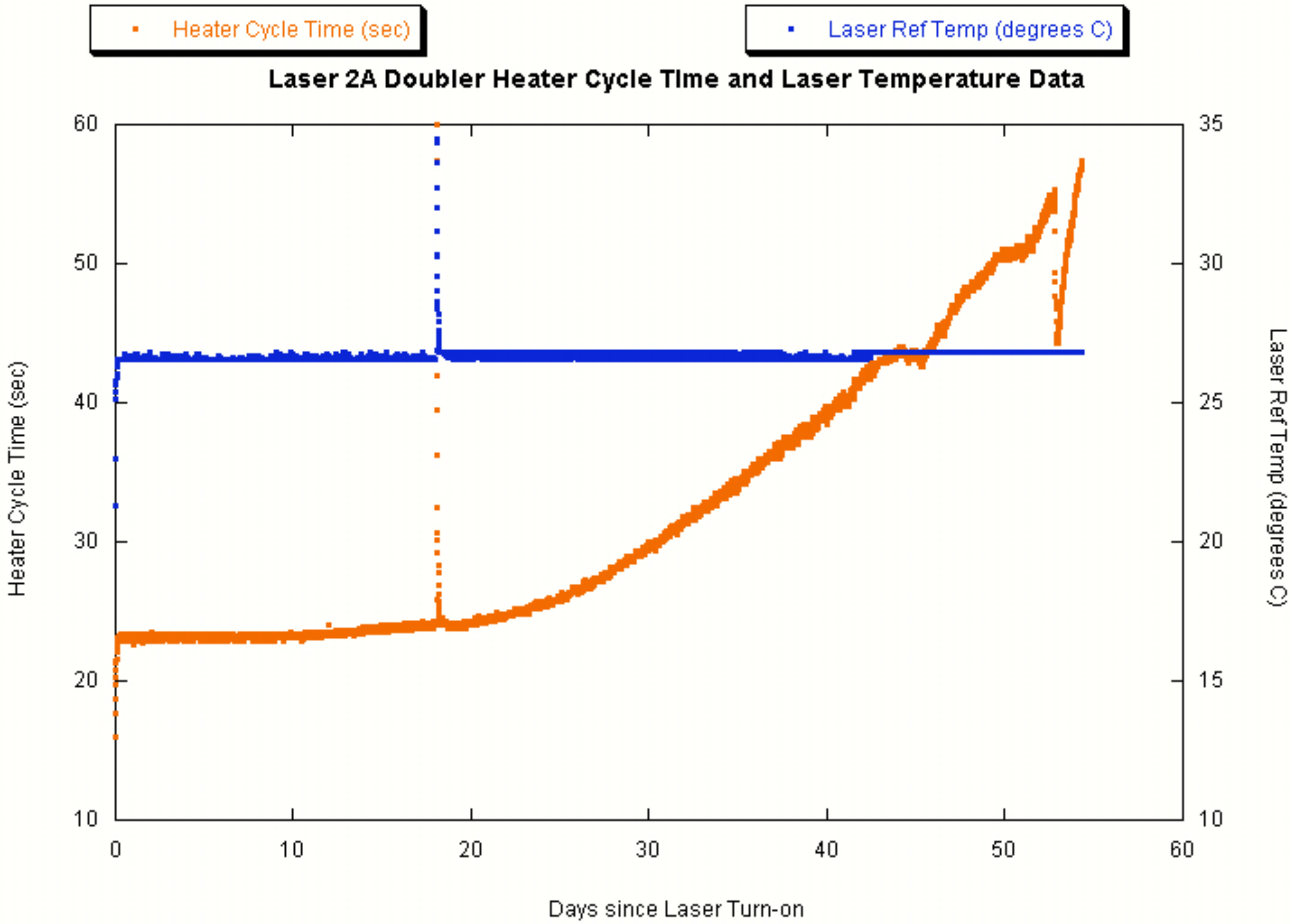
Laser 2 Campaign



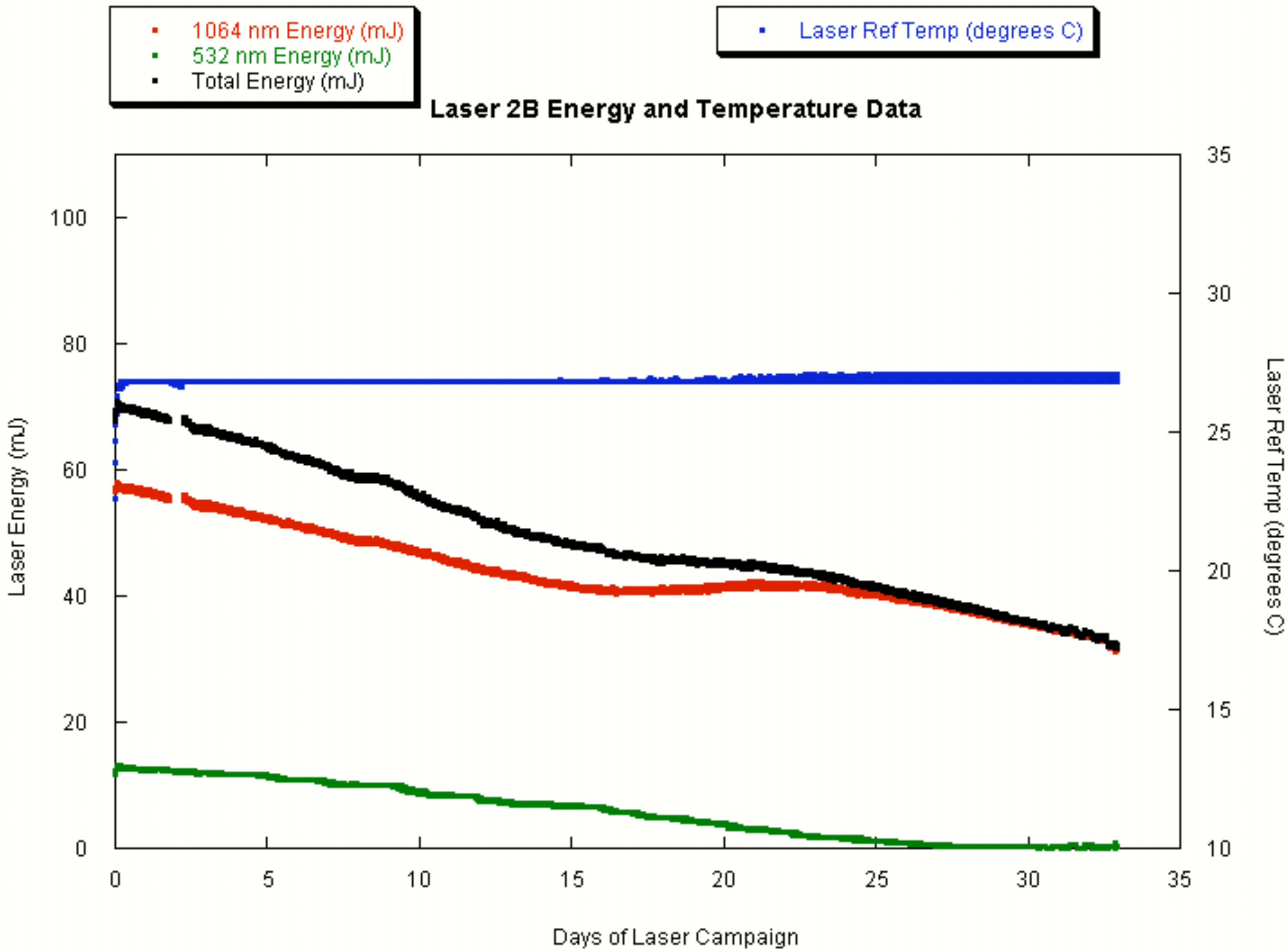
Laser 2A Campaign



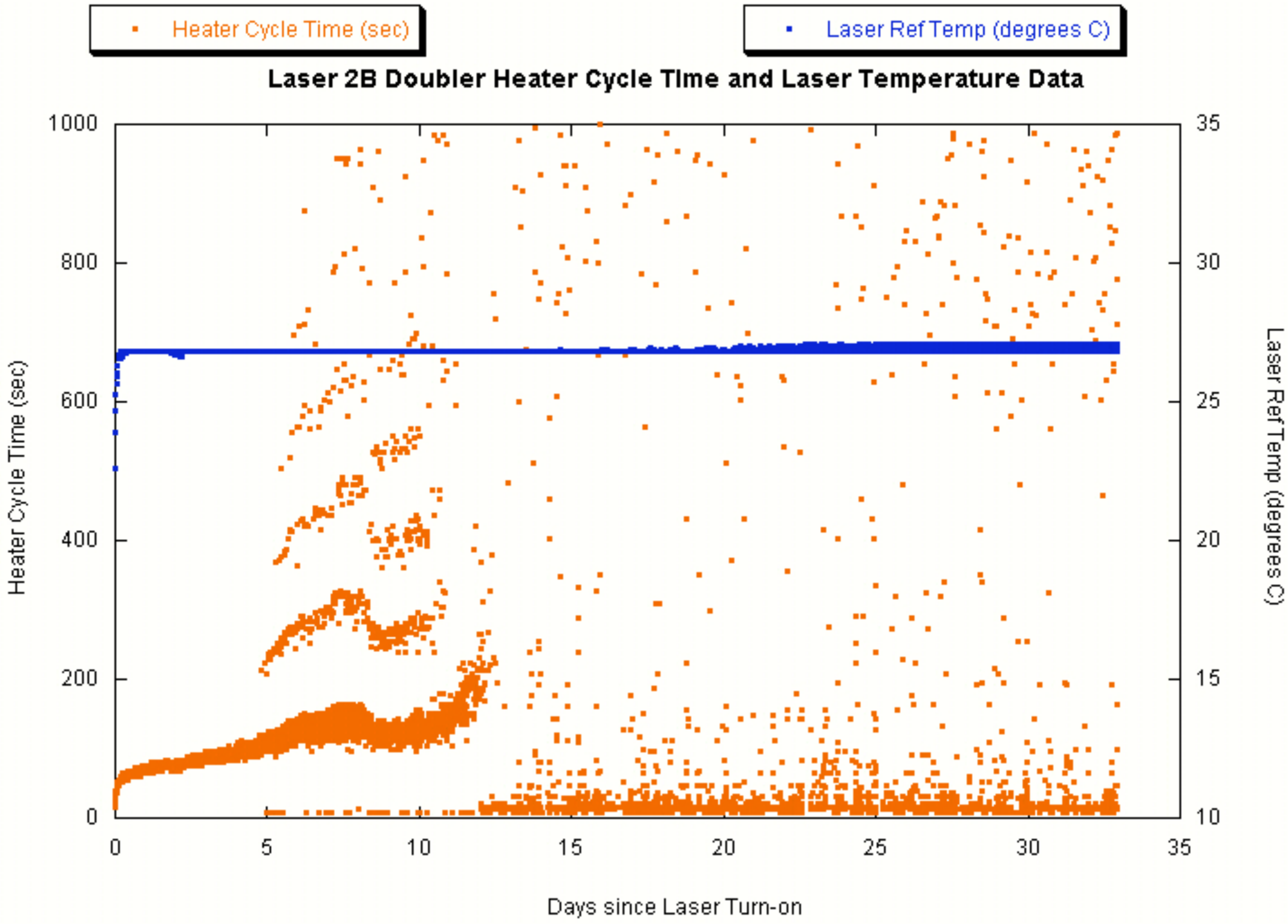
Laser 2A Campaign



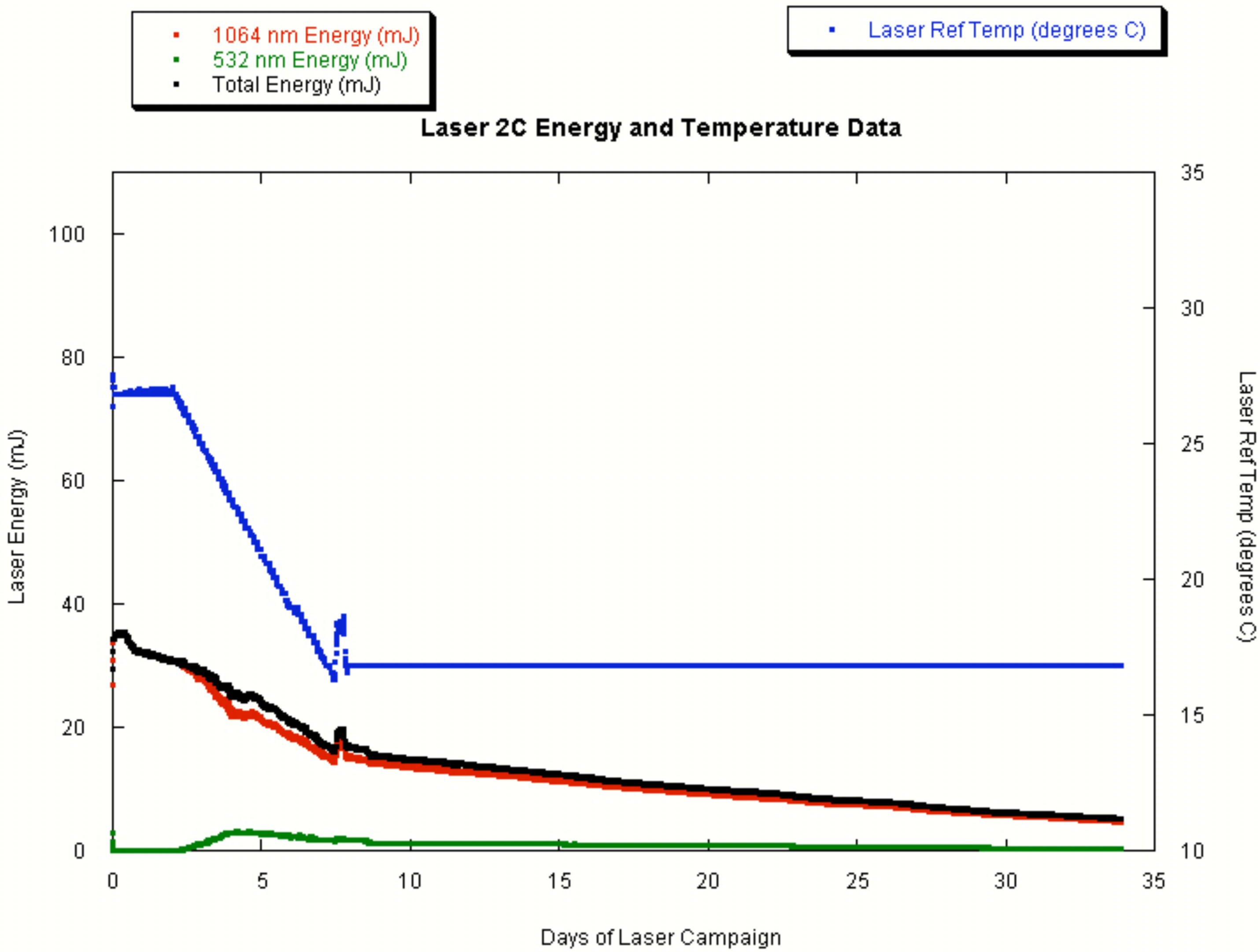
Laser 2B Campaign



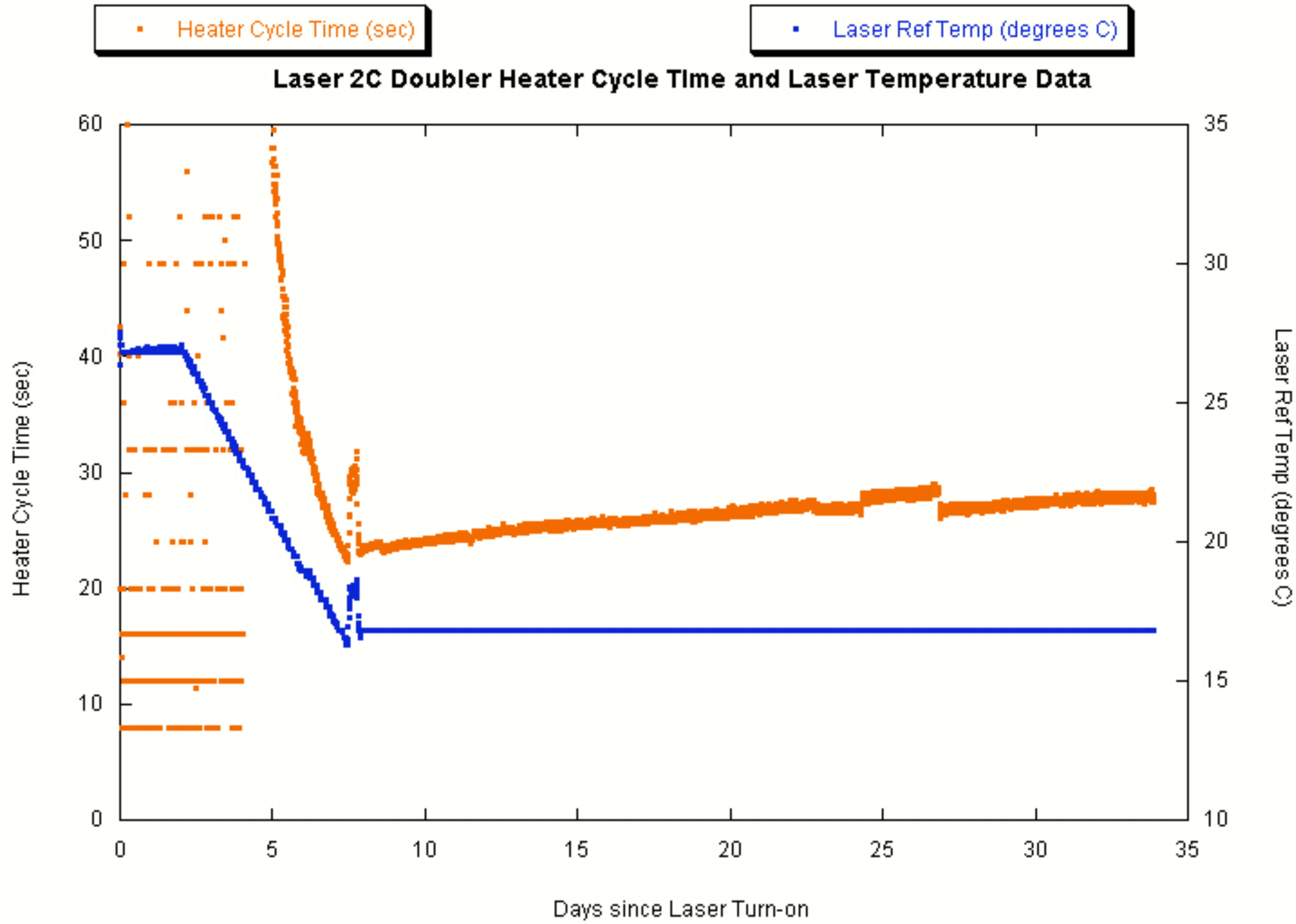
Laser 2B Campaign



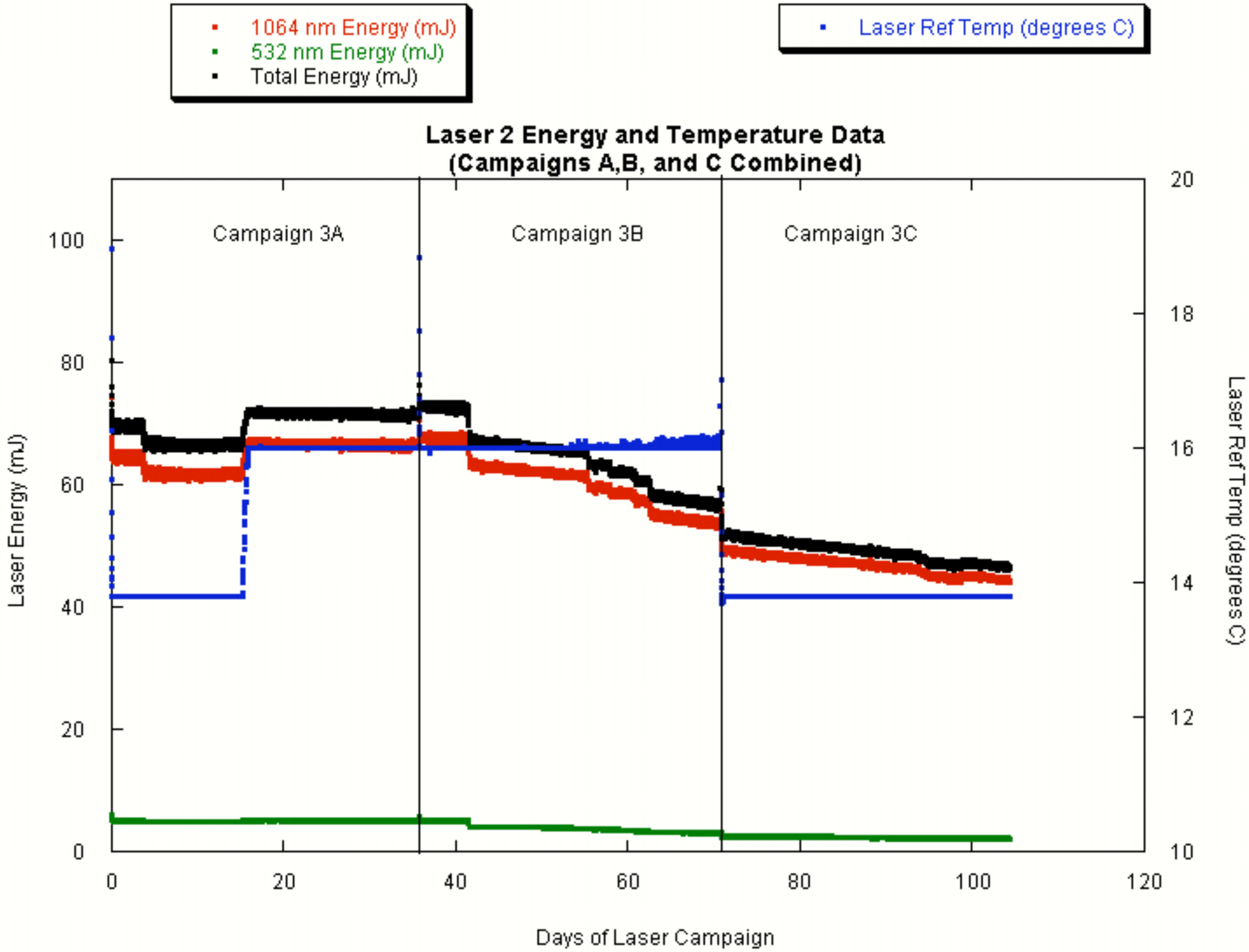
Laser 2C Campaign



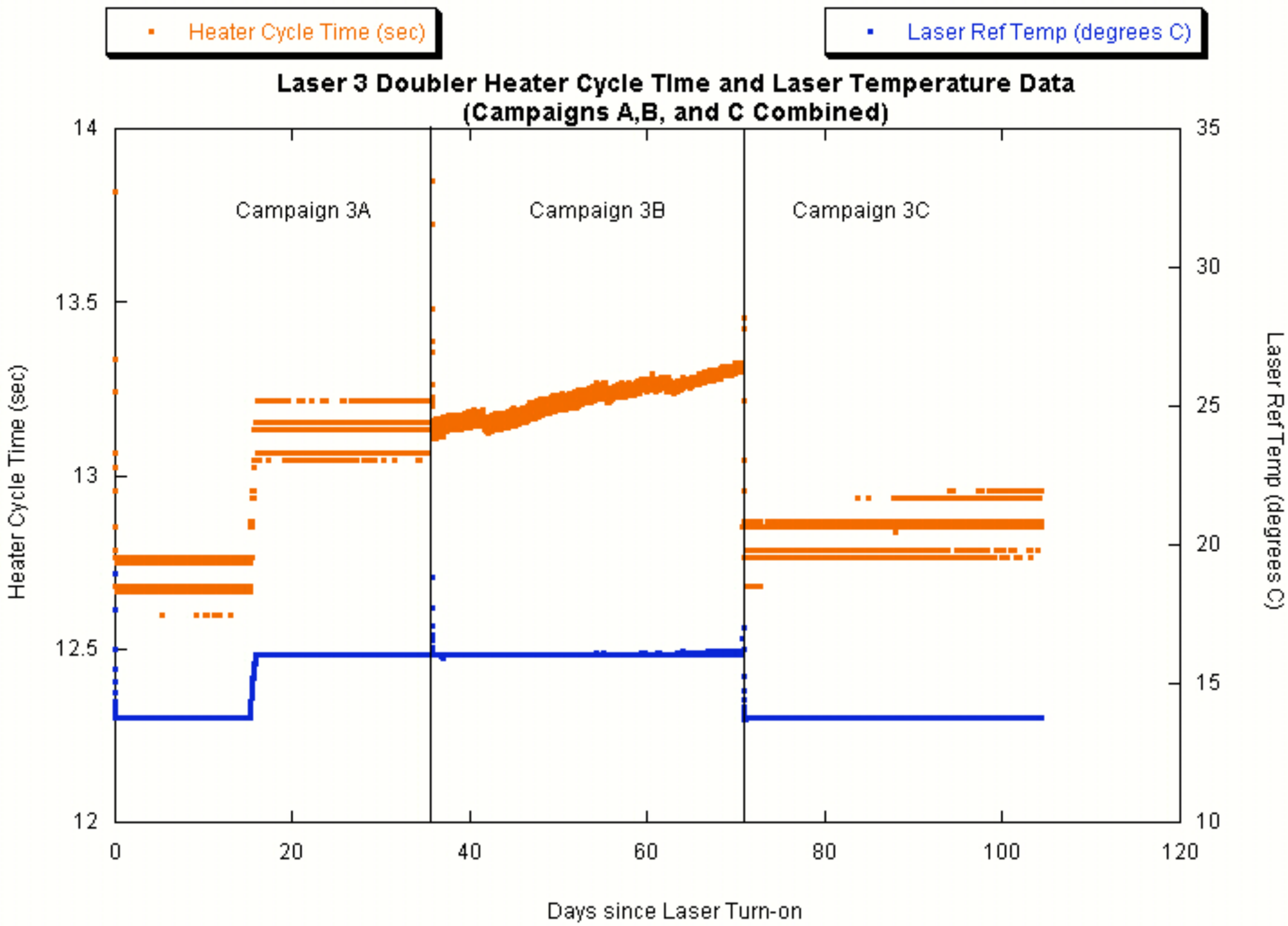
Laser 2C Campaign



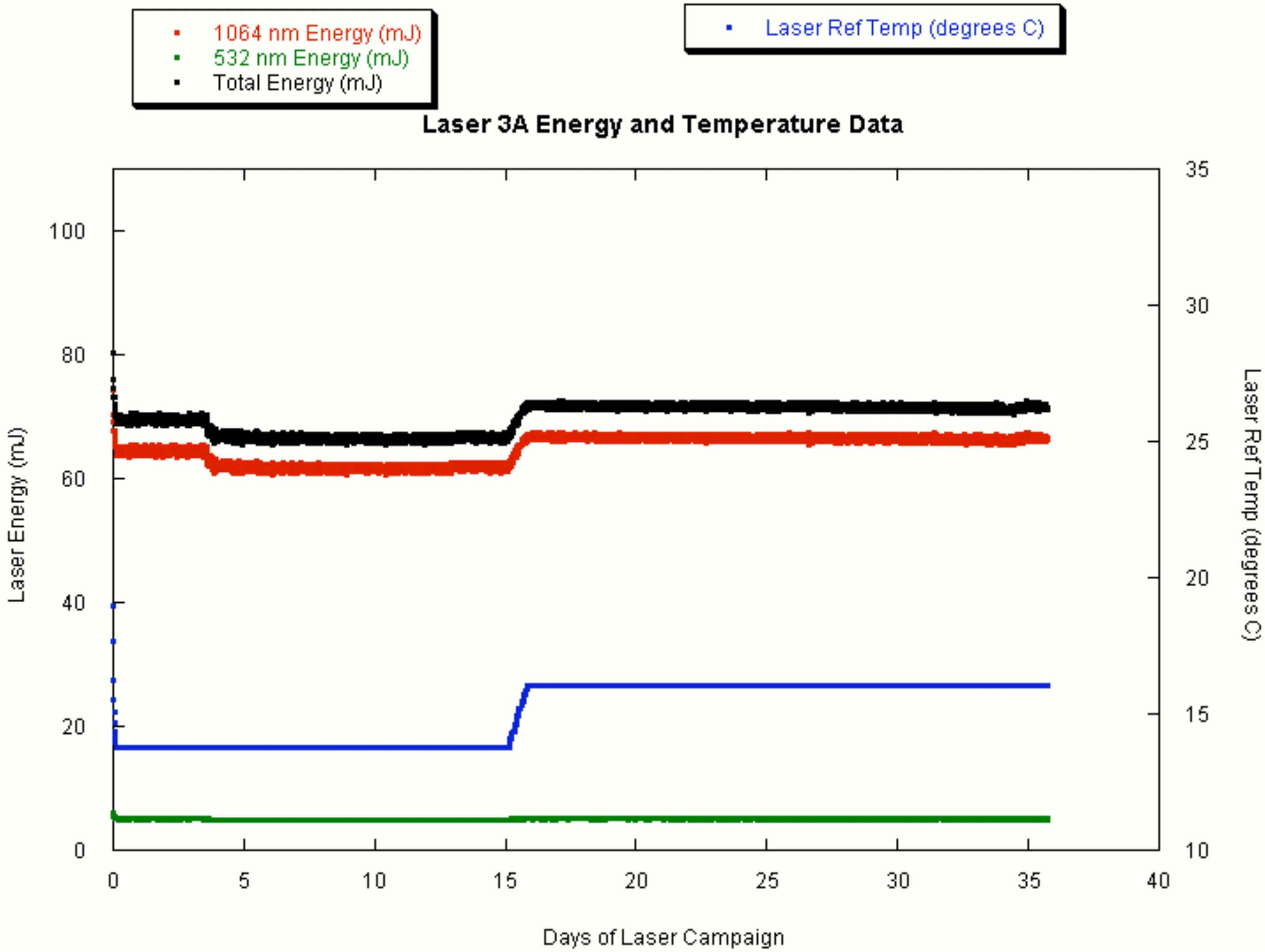
Laser 3 Campaign



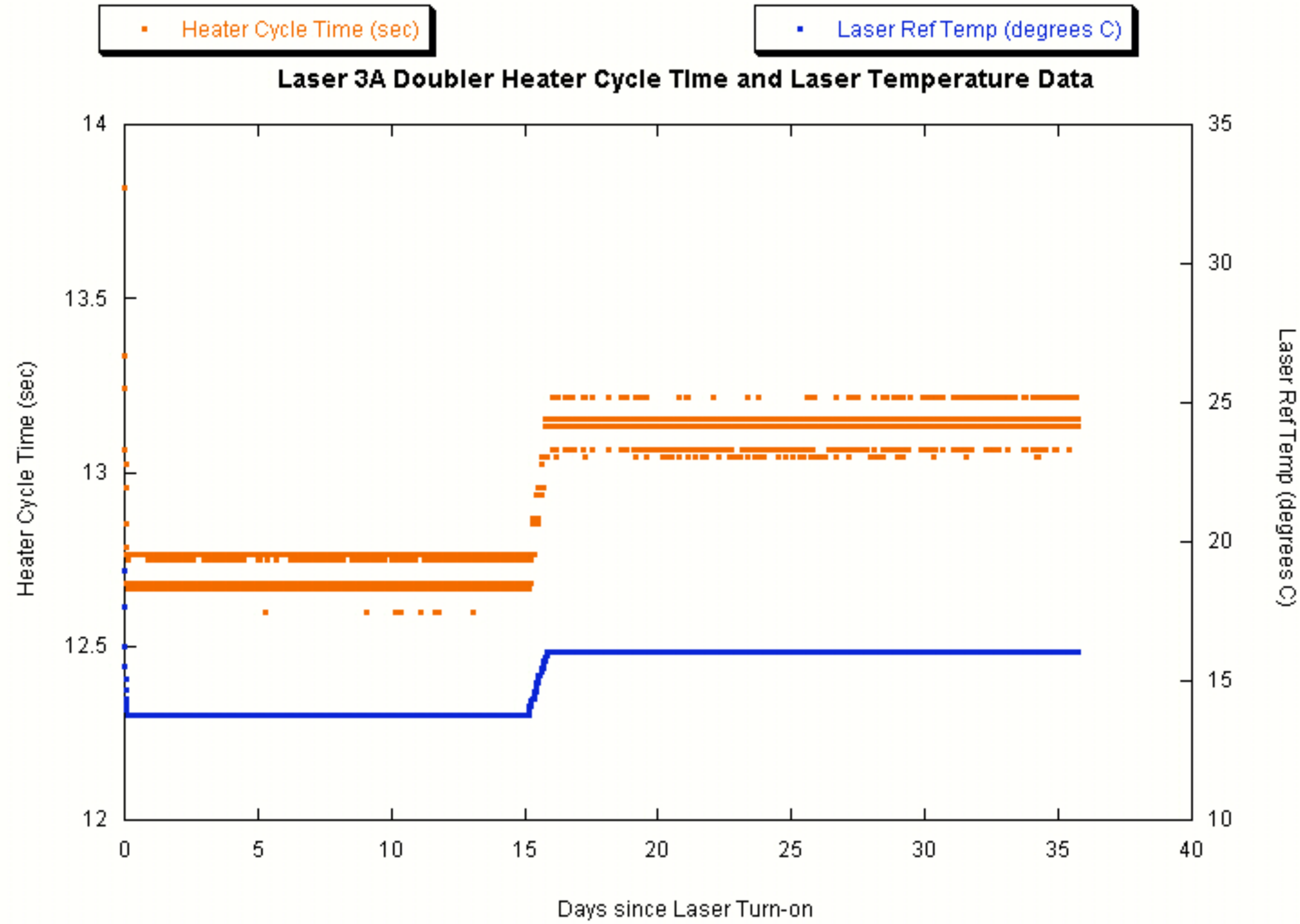
Laser 3 Campaign



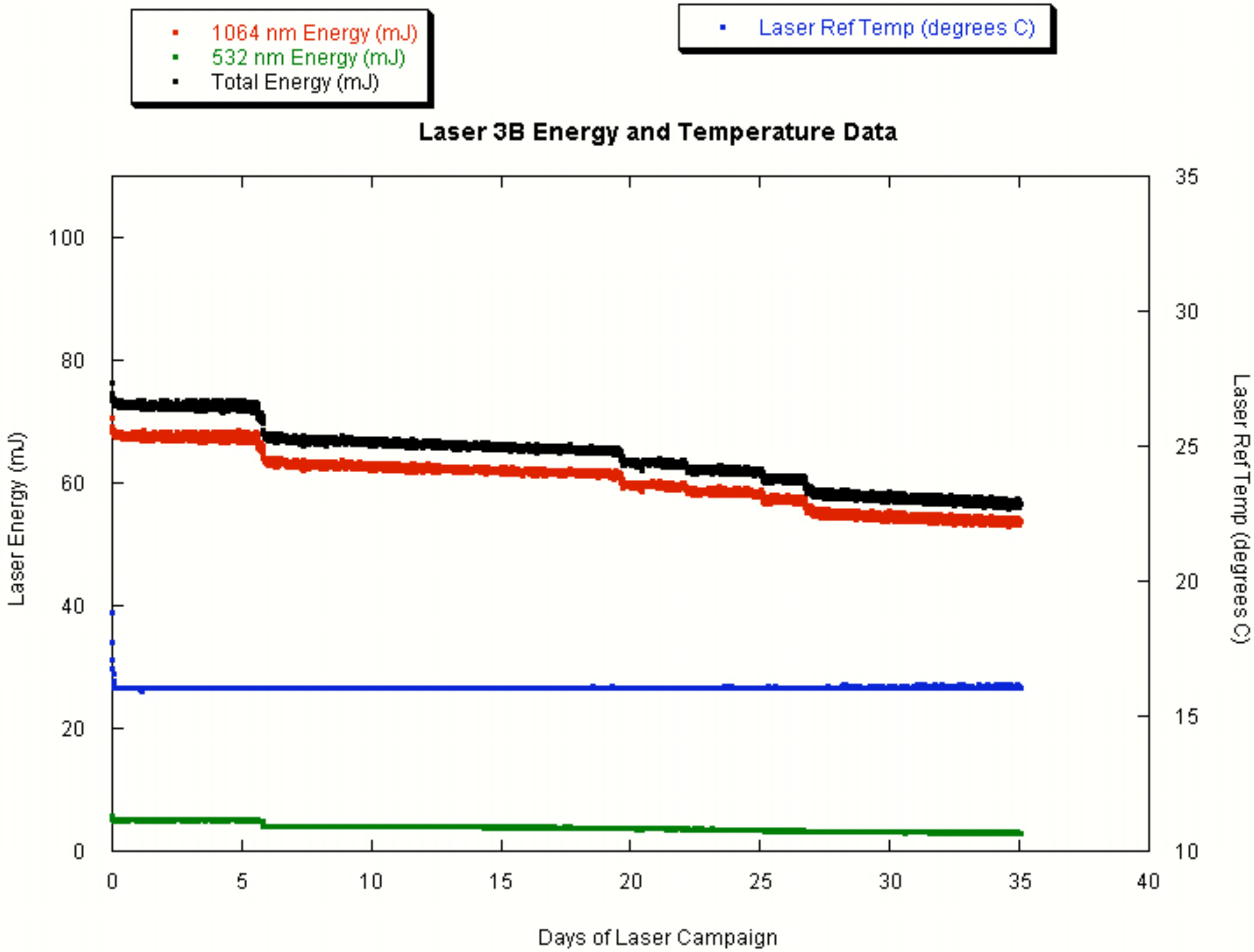
Laser 3A Campaign



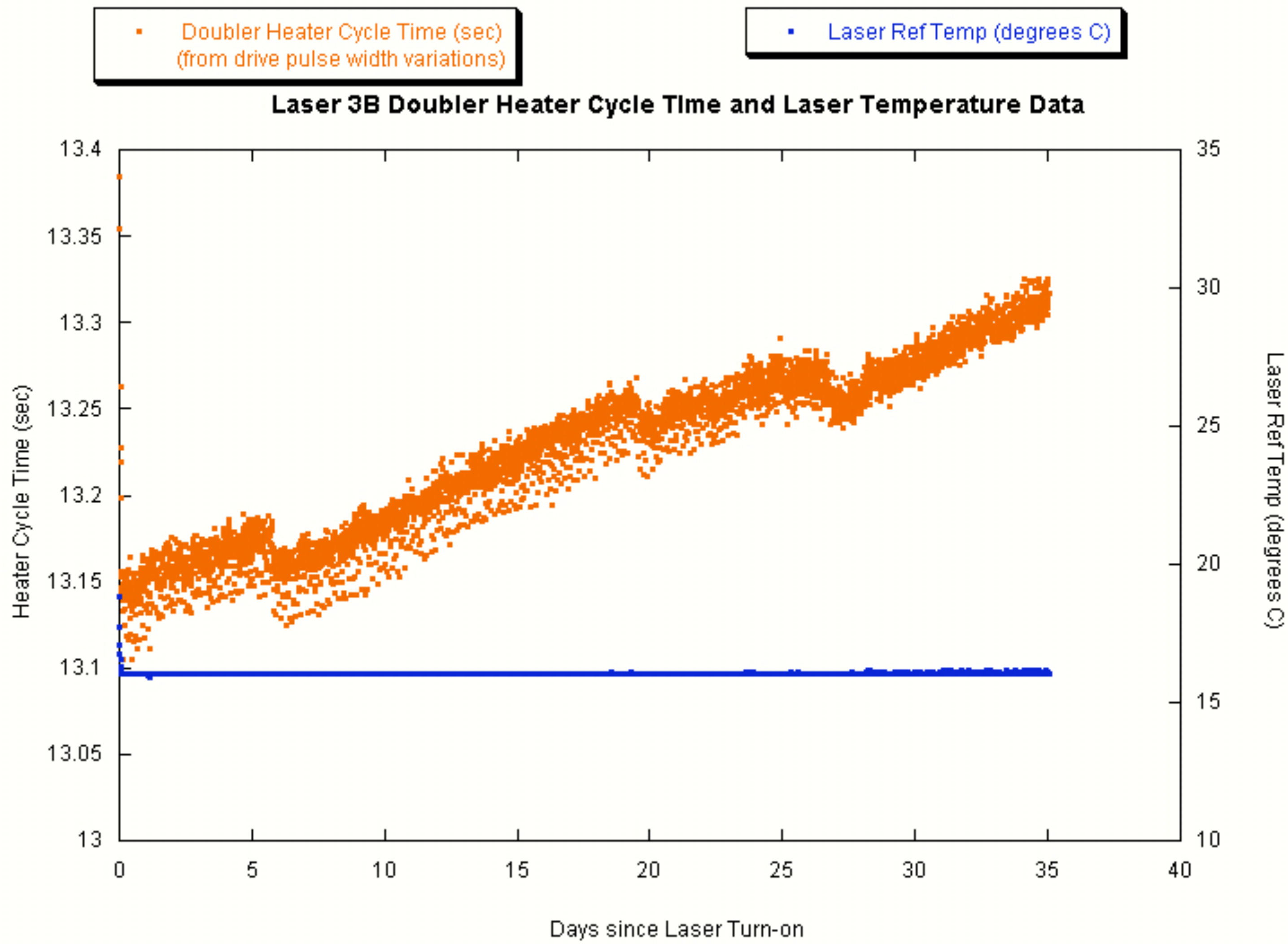
Laser 3A Campaign



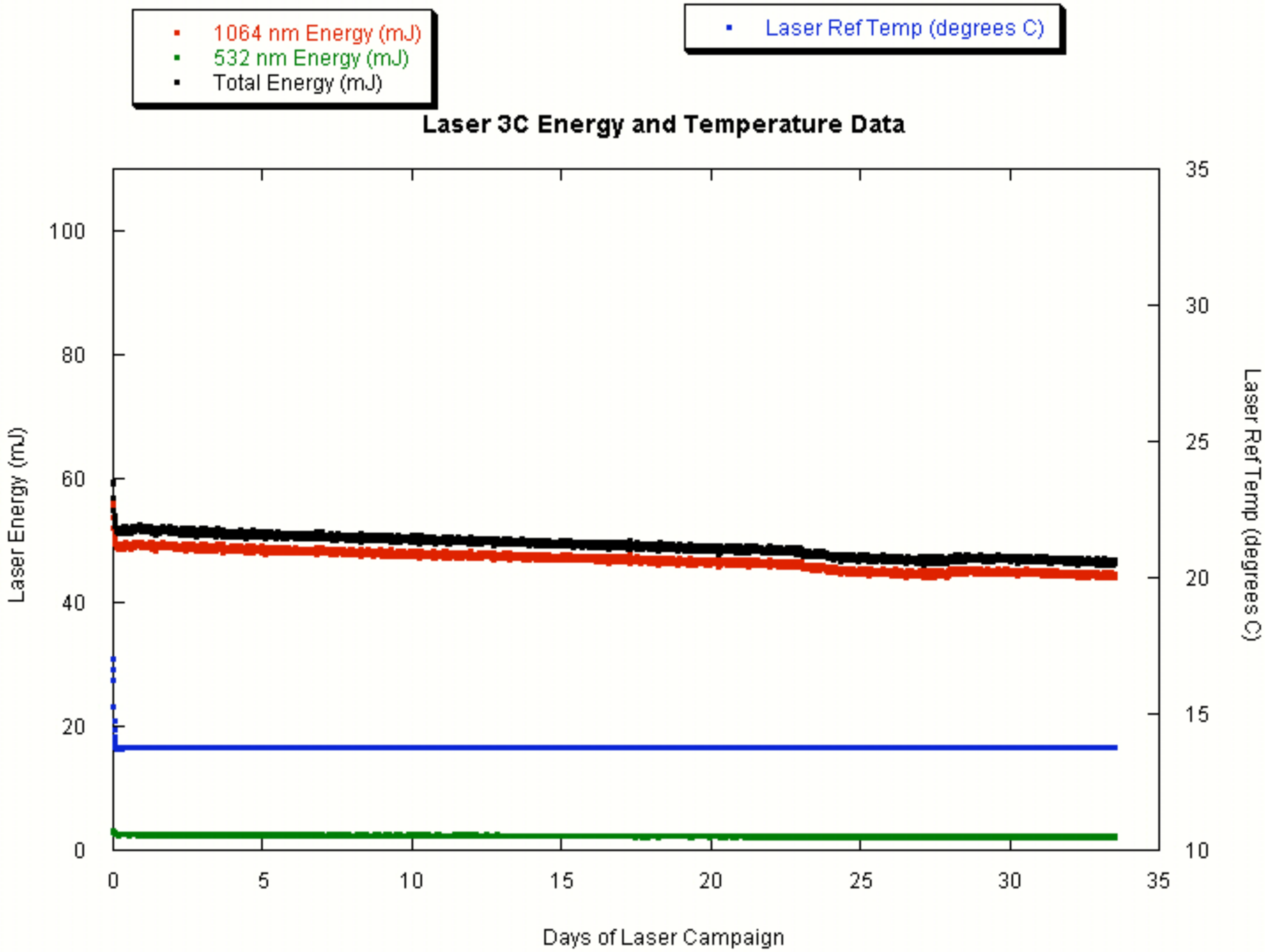
Laser 3B Campaign



Laser 3B Campaign



Laser 3C Campaign



Laser 3C Campaign